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DEPARTMENT OF INTERNAL AFFAIRS

GLACIAL GEOLOGY
OF
NORTHWESTERN PENNSYLVANIA

by
V.C.Shepps
G.W.White
J.B.Droste
R.F.Sitler

TOPOGRAPHIC AND GEOLOGIC SURVEY
BULLETIN G 32
1959

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OF
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DEPARTMENT OF INTERNAL AFFAIRS
Genevieve Blatt, Secretary
TOPOGRAPHIC AND GEOLOGIC SURVEY
Carlyle Gray, State Geologist

1959

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The

GLACIAL GEOLOGY

of

NORTHWESTERN PENNSYLVANIA

by

V. C. Shepps
G. W. White
J. B. Droste
R. F. Sitler

ABSTRACT

Northwestern Pennsylvania is covered with deposits of drift brought by continental sheets which invaded from the north and northeast. Ice moved down the Erie Basin a major lobe known as the Erie Lobe and spread out into northwestern Pennsylvania ce during the Illinoian age and five times during the Wisconsin age of the Pleistocene och.

Tills of the various advances are identified and separated into stratigraphic entities the basis of leaching, texture, color, and soil profile development and are treated as k-stratigraphic units.

The outermost drift of northwestern Pennsylvania is Illinoian in age and extends as - to 14-mile-wide band from Beaver County at the Ohio-Pennsylvania border to Warren unty at the New York border. Two drifts are found in this belt, an outer drift repre- ted by very thin, discontinuous till and erratics; and an inner (younger), thin, but more tinuous fine-grained till.

The Wisconsin drifts are Tazewell and Cary in age, but Tazewell drift was completely ered by later Cary drift and does not appear at the surface. The Tazewell ice deposited ebbly, sand till (Mogadore Till). The outer margin of the Cary drift is marked by the t Moraine composed of sandy loam till and gravel. Behind the Kent Moraine is the Kent und moraine of loam till which blankets most of the surface of northwestern Pennsylvania, numerous kames and kame terraces. North of this ground moraine area is the end mo- ne (the Lavery Moraine) of the next advance; it and the ground moraine behind it are com- ed of silt till and are named for the hamlet of Lavery just west of Edinboro in Crawford unty. Behind and in part compounded with the Lavery Moraine is the Defiance Moraine of next (Hiram) advance. The till deposited in the Defiance Moraine and in the ground mo- ne of this advance is a clay or silty clay till.

Still farther to the north and parallel to the southern shore of Lake Erie is the Ashta- a Morainic System, a series of en echelon end moraines composed of silt till and depos- l by the Ashtabula advance, the last advance of Cary time and the last ice to enter Penn- vania. The Ashtabula Moraines override the Defiance Moraine in part. Lake deposits l down after the Ashtabula ice had retreated blanket the plain south of present Lake Erie.

INTRODUCTION

General Statement

This report presents a study of the character, distribution, and history of the glacial deposits of northwestern Pennsylvania. Material for this paper is compiled from studies by a number of workers under the direction of George W. White of the University o Illinois. The field and laboratory studies were undertaken as part o a larger project on the "Constitution of glacial till" being conducted at the University of Illinois with the aid of grants from the National Science Foundation and the University of Illinois Research Board. Field work was supported in part by the Pennsylvania Geological Survey.

The area included in the study covers all of Erie, Crawford, and Mercer counties and parts of Warren, Venango, Butler, Lawrence, and Beaver counties. The initial mapping was done by Vincent C. Shepps (1955) during the summers of 1952 and 1953 in close connection with work being done nearby in Ohio by George W. White for the U. S. Geological Survey (White, 1950, 1951 a & b, 1953 a, b, c, & d; White and Shepps, 1952). The work was continu and extended to the south during the summers of 1954 and 1955 by Robert F. Sitler (1957). To complete the study of all of northweste Pennsylvania, John B. Droste with the assistance of Robert W. Doe ler in 1956 and James C. Tharin in 1957 mapped the remaining are during the summers of 1956 and 1957. Though the latter mapping was not intended to serve as a thesis, publications as well as a thes were based upon material collected during this field work (Droste, 1956 a & b; Droste and Doehler, 1957; Droste and Tharin, 1958; Tharin 1958). The areas studied by the various workers are shown on Plate 1.

Samples collected during field work were subjected to labor tory analysis at the University of Illinois. These analyses provide information on the character of the material deposited by the ice. This information not only allowed more accurate mapping of the deposits but also permitted more precise descriptions of the sediments. Data and techniques produced as a result of the laboratory work have been published in part (White and Shepps, 1952; Shepps, 1953, 1958; Sitler and Chapman, 1955; Droste, 1956 a & b; Droste and Doehler, 1957; Droste and Tharin, 1958; Tharin, 1958; White, 1957; White et al, 1957).

Although many publications were issued on the glacial depos of northwestern Pennsylvania in the past, very few were based on detailed mapping of the deposits. Past workers recognized that ice had advanced into the area more than once, but, except for cClintock and Apfel (1944), no attempts had been made to date her the main advance or the later Wisconsin advances in terms of subdivisions mapped in adjacent states. It is the purpose of this er to present detailed mapping of the various glacial deposits of rthwestern Pennsylvania and to relate wherever possible the age these deposits to the classic region of the Mississippi Valley.

Acknowledgments

The authors wish to acknowledge the cooperation and support the late Stanley H. Cathcart of the Pennsylvania Geological Survey l of Carlyle Gray, present State Geologist of the Pennsylvania Geol- cal Survey. They wish also to acknowledge the support of the tional Science Foundation and the University of Illinois Research ard; and the technical advice on sedimentation, mineralogic and rographic problems given by Professors Jack L. Hough, Ralph Grim, and Carleton A. Chapman; all of the University of Illinois. ey also acknowledge the able assistance in laboratory studies of C. Tharin, who served as research assistant to G. W. White m 1956 to 1959.

Previous Work

Erratics in northwestern Pennsylvania were first noted in 1810 Thomas Nuttall (1950/51, p. 39, 42) who did not speculate on their gin. He correctly interpreted a ridge near Erie as "a former ndary of the lake" (p. 44). In 1816 David Thomas commented on ridges at and south of Erie which we now know to be beach ridges l moraines, but did not realize their origin (Thomas, 1819, p.35). e reports of the First Geological Survey of Pennsylvania by Rogers 58) gave only incidental notice to the "glacial deposits" of Pennsyl- ia. Although the glacial origin of the deposits was becoming gen- lly accepted by the time of the First Survey, Rogers was not con- ced and, in the report of the First Survey, offered evidence to re- e the glacial origin.

By the time of the Second Geological Survey of Pennsylvania glacial theories had become widely accepted. Descriptions of cial deposits, straie, etc., accompanied every bedrock report in northwestern counties (Carll, 1875, 1880, 1883; White, I.C., '8, 1879, 1880, 1881). A special study of the glacial boundary was de by H. C. Lewis assisted by G. F. Wright and was published as ort Z of the Second Pennsylvania Survey (Lewis, 1882). In this ort the outer limit of the Wisconsin terminal moraine was traced oss Pennsylvania. From time to time, J. P. Lesley, Director the Second Survey, included comments on glacial erosion and dep- tion in his letters of transmittal which accompanied reports on the glaciated areas (letters of transmittal in White, I. C., 1878, 1879, 1880, 1881; Carll, 1875, 1880, 1883). The most complete discussio of the glacial geology of northwestern Pennsylvania came as a result of the work of T. C. Chamberlin and Frank Leverett. Chamberlin worked in the area of the terminal moraine and published preliminar reports on the terminal moraine (Chamberlin, 1883) and on the glaci border (1890). Leverett, working under the direction of Chamberlin studied the areas behind the terminal moraine and combining Chambe lin's work with his own, compiled a monograph entitled "The Glacial Formations and Drainage Features of the Erie and Ohio Basins" (Leverett, 1902).

Few papers dealing with the glacial deposits of northwestern Pennsylvania have been published since the appearance of Leverett's monograph in 1902. Only a few papers – one by Leverett (1934), on by Frank DeWolf (1929) and a recent one by Arthur Preston (1950) – can be described as reports of glacial geology based upon original work. Leverett's paper deals largely with the pre-Wisconsin deposit Preston describes pro-glacial lakes formed by damming of water in front of advancing Wisconsin age ice. In addition to these three papers, two other bedrock reports include a discussion (with maps) of the glacial deposits within the area studied (Butts, 1910; Richardson, 1936).

BEDROCK

Northwestern Pennsylvania is underlain by rocks which range in age from lower Upper Devonian to middle Pennsylvanian. Going southward from Lake Erie, successively younger rocks are crossed so that the oldest rocks in the area are exposed along Lake Erie and the youngest are in the southernmost part of the area. All of the bed throughout northwestern Pennsylvania dip to the south or southeast o are horizontal. In general the rock types which predominate at the surface are shales, siltstones, and platy sandstones. Limestones a massive coarse-grained sandstones form only a very minor part of the surface rocks.

Northern Erie County is underlain by shales and siltstones of the Devonian Canadaway and Conneaut Formations. The Cattaraugus shales, sandstones, and redbeds also of Devonian age underlie most of southern Erie County and northern Crawford and Warren counties. Crawford and Warren counties also contain sandstones and shales of the Pocono Formation (Mississippian) with rocks of the Pottsville Group (Pennsylvanian) capping the southern uplands. Pottsville shal and sandstones predominate in Mercer and Venango counties except the northern lowlands which contain Pocono Formation rocks, and in the southern uplands which are capped by the coal measures of the

egheny Group (Pennsylvanian). The Allegheny beds which include
le, sandstone and some coal and limestone cover the surface of
st of Lawrence and Butler counties. Pennsylvanian Conemaugh
les cap the southern uplands of Lawrence and Butler counties and
erlie most of Beaver County within the glaciated area.

PHYSIOGRAPHY

The major part of northwestern Pennsylvania lies within the
palachian Plateau physiographic province of Fenneman (1928). A
all part along Lake Erie is within the Central Lowlands physio-
phic province.

TOPOGRAPHY

Elevation and relief in northwestern Pennsylvania increase
m the northwest toward the east, the southeast, and the south.
surface in western Erie and Crawford counties ranges in elevation
m 573 feet at Lake Erie to slightly above 1000 feet, but the local
ief seldom exceeds 100 feet. East from these counties the surface
es and becomes more dissected until in Warren County, high eleva-
ns exceed 2100 feet, and relief has increased to 600 to 800 feet.
thward and southeastward from Erie and Crawford counties eleva-
ns rise along with relief, but to a lesser extent than toward Warren
nty. In southern parts of the area elevations reach 1200 to 1500
t and relief is of the order of 300 to 500 feet.

Two erosion surfaces are present within the area (Cole, 1937,
146), the Lexington surface at a general elevation of 1250 feet and
Allegheny surface at a general elevation of 1550 feet. The Alle-
ny surface which slopes gently westward is exhibited in all of the
as except in the Girard, Linesville and Fairview quadrangles and
portions of the Beaver, Neshannock, Shenango, Erie, and Northeast
drangles. The surface in these areas is the Lexington surface.

Maximum relief in all cases is found outside of the glacial
der. Just behind the glacial border, in the area of the main ter-
al moraine, relief is locally reduced to as little as 50 feet by the
ing of pre-existing topography by glacial deposits. This, along
the very knobby surface developed on the terminal moraine,
ates a striking contrast between the glaciated and the non-glaciated
as.

The surface before the advance of the ice was a youthful to
urely dissected plateau. Dissection had proceeded farthest in the
t and southeast as witnessed by the increasing relief in those

directions. The present surface throughout northwestern Pennsylvania exhibits a masked erosional topography. Seldom has glacial filling or erosion been sufficient to hide the pre-glacial topography. A few miles south of Lake Erie is a north-facing escarpment paralle to the lake formed upon resistant rocks of the Devonian Conneaut Fo mation. This escarpment is more pronounced near the New York border but flattens and becomes obscure westward.

A special type of glacially-induced topography exists in the area northeast of Edinboro in Crawford County. The surface consist of a series of long, smooth parallel ridges with intervening valleys. The ridges are consistently oriented in a N35°W direction and frequently are unbroken for a mile or more. Relief between the valley bottom and ridge top is generally 40 to 60 feet, but may be as much as 100 feet. Individual ridges are long and narrow with more or les level crest lines throughout their length, differing in these respects from typical drumlins. These features might best be called "corrugation topography" because of the resemblance to corrugated cardboard (Shepps, 1955, p. 10). They resemble "flutings" in Alberta described by Gravenor and Meneley (1958). Figure 1 shows a map drawn from aerial photographs of the drainage and ridge crests in this area. This type of topography might be considered as a transition zone into an area of drumlins to the east, as proposed by Holme (1949, p. 1433).

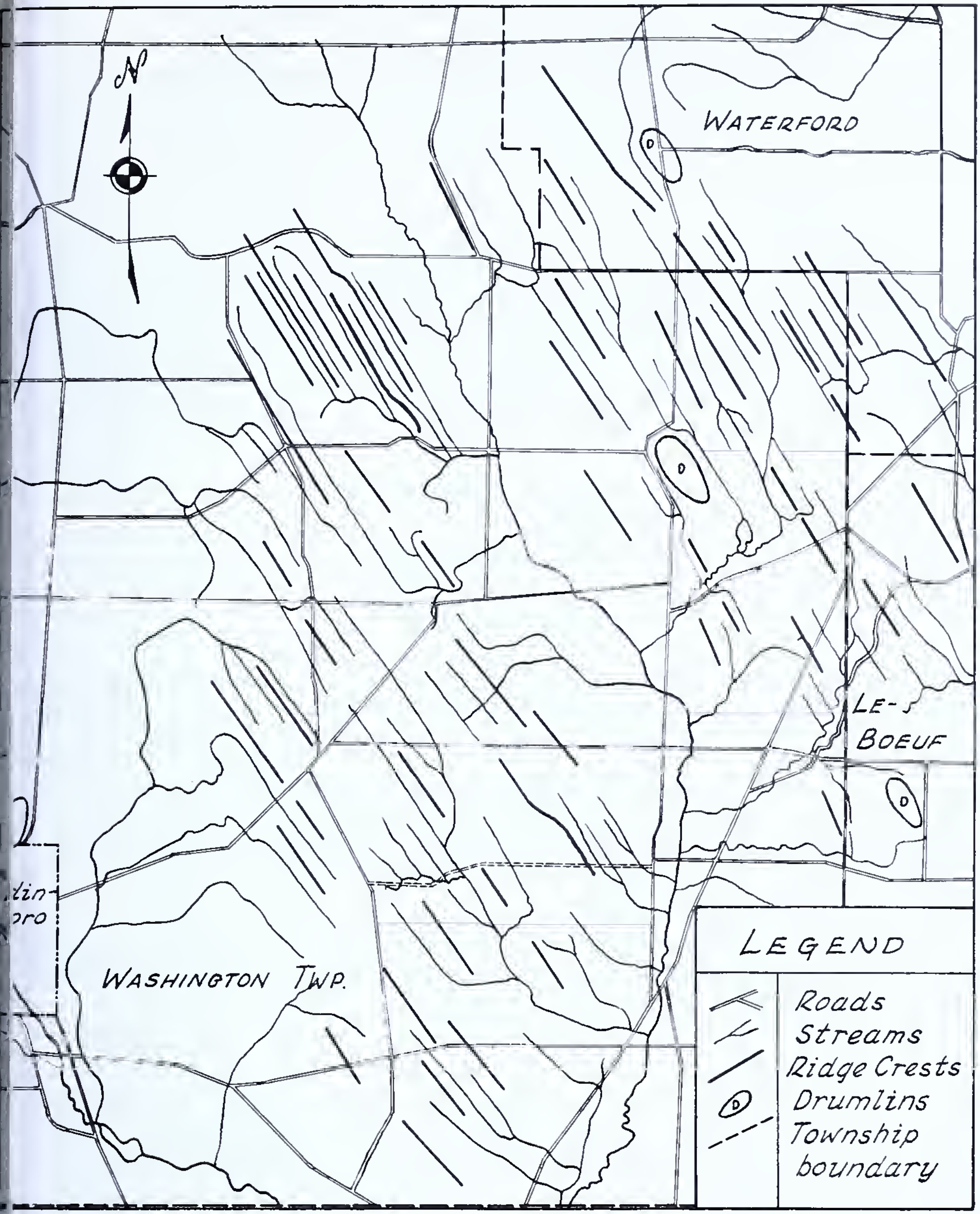
DRAINAGE

Nearly all of northwestern Pennsylvania is drained by the Oh River and its tributaries the most prominent of which is the Alleghen River. The Allegheny River flows outside of the glacial border, wat from the glaciated area being brought to it by tributary streams whic include Brokenstraw Creek, Oil Creek, French Creek, and Sandy Creek. Other drainage flows down the Shenango River and Mahoning Slippery Rock, and Neshannock creeks to the Beaver River and thenc into the Ohio River at Beaver, Pennsylvania.

A small part of the drainage from northwestern Pennsylvania is northward into Lake Erie and thence by way of Lake Ontario and the St. Lawrence River to the Atlantic Ocean. Most of this drainage is through short-coursed streams such as Elk Creek and Walnut Creek.

EARLY DRAINAGE SYSTEMS

In contrast to the present drainage, the preglacial drainage in northwestern Pennsylvania was predominately toward the north and to the Atlantic Ocean by way of the St. Lawrence Valley. With the advance of ice from the north, streams flowing northward were



se from Cambridge Springs topographic quadrangle
dge crests and drainage from aerial photographs

SCALE
0 1 Mile

gure 1. Orientation of surface features in the area of "corrugation topography" in Crawford County, Pennsylvania.

ponded, forced to overflow low cols, and in many cases were rerouted to flow southward. The distribution of the streams prior to the ice advances is shown by Leverett (1934, p. 93). Reversal of the entire preglacial drainage may not have been accomplished during a single ice advance but may have been brought about by a series of changes during each succeeding advance.

Complete reversal of drainage within old channels was possible because earlier channels were filled or partially filled with glacial material, the new courses being developed on top of the fill. In some cases what may have been major drainageways were nearly abandoned and now carry only minor tributaries. A map showing the location of most of these filled or buried valleys is shown by Leggette (1936, Pl. 2).

GLACIAL GEOLOGY

Introduction

GENERAL STATEMENT

Continental ice sheets advanced at least seven times into northwestern Pennsylvania during the Pleistocene Epoch. Ice moved first into the Erie Basin as a major tongue known as the Erie Lobe. As the Erie Lobe advanced it subdivided into smaller sublobes as shown in Figure 2. The invasions into Pennsylvania occurred as a southeastward expansion of the Grand River Lobe, except for the last which was only a lateral spreading of the Erie Lobe itself.

The various advances into Pennsylvania are listed in Figure 3. Deposits in northwestern Pennsylvania have been correlated with the deposits of eastern Ohio mapped by White (1953 a, p. 18; 1953 d, Pl. 26; White et al, 1957). Figure 3 shows the time-stratigraphic terminology applied to the various advances and the rock-stratigraphic names applied to the deposits of those advances. Some names used in the recent past ("early Cary", etc.) for stratigraphic units are more properly time terms and are now replaced by rock-stratigraphic names (White, in press). The names used earlier are included in Figure 3 for reference.

Ice advanced into northwestern Pennsylvania during at least two stages of the Pleistocene - the Illinoian and Wisconsin stages. Within the Illinoian Stage two advances are indicated. Five advances are known to have occurred during Wisconsin time - one during the Tazewell Substage and four during the Cary Substage. After the Cary Substage ice advances failed to reach Pennsylvania. The extent of each of the advances is shown in Figure 4 and in detail on the glacial map (Pl. 1). On the map the outer limit of each advance is shown by

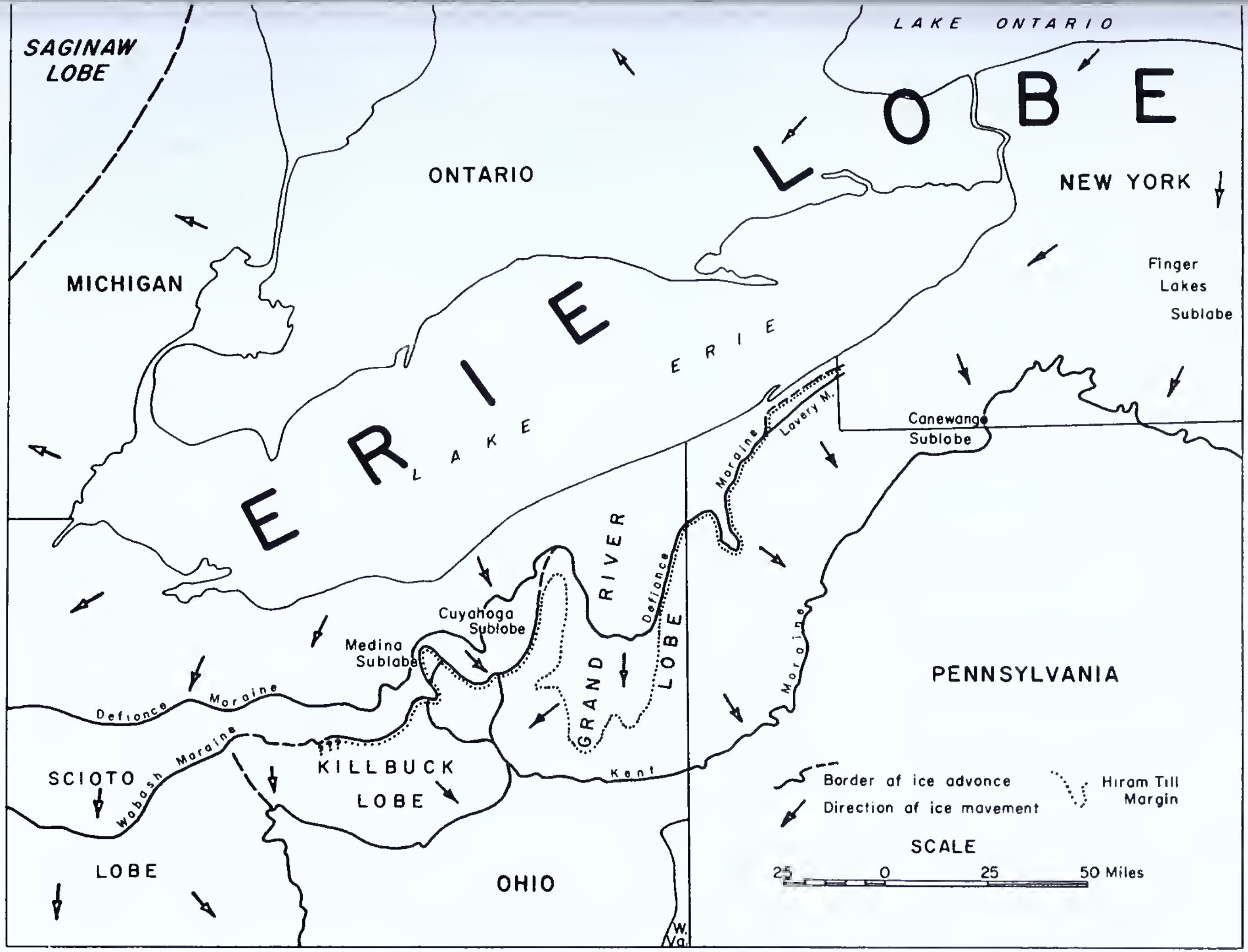


Figure 2. Distribution of the various ice lobes in western Pennsylvania and adjacent areas.

		AGE	DEPOSITS	FEATURES	FORMER NAMES
PLEISTOCENE SERIES	WISCONSIN STAGE	Cary Substage to Recent time	Sands and gravels, silts and clays	Beach deposits of lakes in the Erie basin	
		Cary Substage			
		Ashtabula advance	Ashtabula Till	Ashtabula Morainic System	"latest Cary" Lake Escarpment Morainic System (Leverett, 1902)
			Sand and gravel	kames and outwash	
		Hiram advance	Hiram Till	Defiance Moraine ground moraine	"late Cary" Inner Cleveland moraine (in part) of Leverett, (1902)
			Sand and gravel, silt and clay	kames, outwash, and lake deposits	
		Lavery advance	Lavery Till	Lavery Moraine ground moraine	"middle Cary" Inner Cleveland moraine (in part) of Leverett (1902)
			Sand and gravel, silt and clay	kames, outwash, and lake deposits	
		Kent advance	Kent Till	Kent Moraine ground moraine Clymer and Findley Lake recessional moraines	"early Cary" Main terminal moraine of Lewis (1882) Inner and outer Cleveland moraines (in part) of Leverett (1902)
			Sand and gravel	kames and outwash	
		Tazewell Substage Mogadore adv.	Mogadore Till	ground moraine in subsurface	
	ILLINOIAN STAGE	"Inner phase" advance	Thin till, sand and gravel	ground moraine, kames, and outwash	
		"Outer phase" advance	Erratics	ground moraine (?)	

Figure 3. Classification and nomenclature of the glacial deposits of northwestern Pennsylvania.

the outer limit of deposits by each ice sheet.

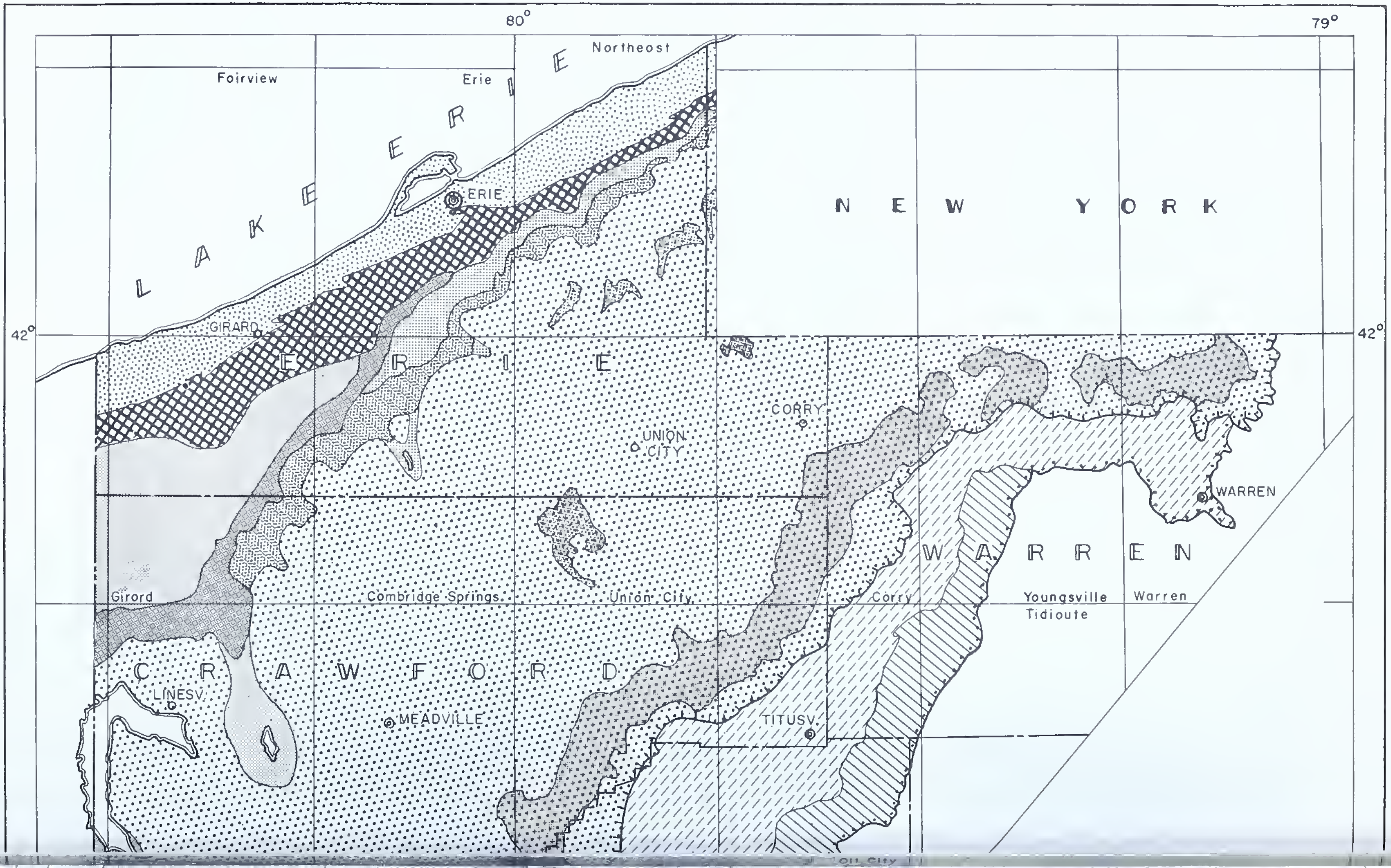
No attempt is made in Figure 4 to show the extent to which ice retreated between each advance. In most cases the extent to which the ice retreated between each advance is known only in a general way. The extent of the retreat is indicated in part by the length of time of the period between the advances. The longest break (interglacial period) between advances was between the advance of the last Illinoian ice and the first Wisconsin ice. Within the Wisconsin Stage the greatest time break appears to have been between the Tazewell advance and the first Cary advance. The second longest break was between the first and the second advances in the Cary Stage. Between the later Cary advances ice may have retreated only a short distance north of Pennsylvania, perhaps not out of the Erie Basin. A short time break is indicated between these advances.

GLACIAL DEPOSITS

During each advance of the ice, materials were picked up both locally within northwestern Pennsylvania, and from places to the northeast. These materials were carried along by the ice for varying distances and were finally deposited in one form or another. The greatest percentage of the material was laid down directly from the ice indiscriminately over the landscape in the form of ground or end moraines composed of a material called till. The remainder of the deposition was from meltwaters flowing under the ice, through fissures in the ice, or issuing from the front edge of the ice. These deposits are variously known as kames, kame terraces, kame moraines, eskers, or valley trains and consist of well- to poorly-bedded sands, silts, clays, and gravels.

Correlation and dating of the ice advances is based largely upon study of the tills. The dating of water laid deposits is more difficult and generally less reliable. Criteria used to identify tills of each advance include (1) the depth to which the carbonates are leached, (2) the degree of development of the soil horizons, (3) the texture of the material, (4) the till mineralogy, (5) the topography developed on the surface of the till, and (6) the areal and/or stratigraphic position of the till with respect to other tills. In addition to these factors, color and structural differences, or the development of special features such as a unique profile of weathering or associated periglacial features may be present which help to distinguish tills from each other.

When attempting to identify a till, it is necessary to use as many as possible of the above criteria together. Rarely is one factor alone sufficient to make an identification. This is particularly true


80°
79°
42°
42°
Northeast
Fairview
Erie
LAKE ERIE
ERIE
NEW YORK
GIRARD
ERIE
CORRY
UNION CITY
WARREN
WARREN
Girard
Cambridge Springs
Union City
Corry
Youngsville
Warren
Tidioute
CRAWFORD
LINESV.
MEADVILLE
TITUSV.
Oil City

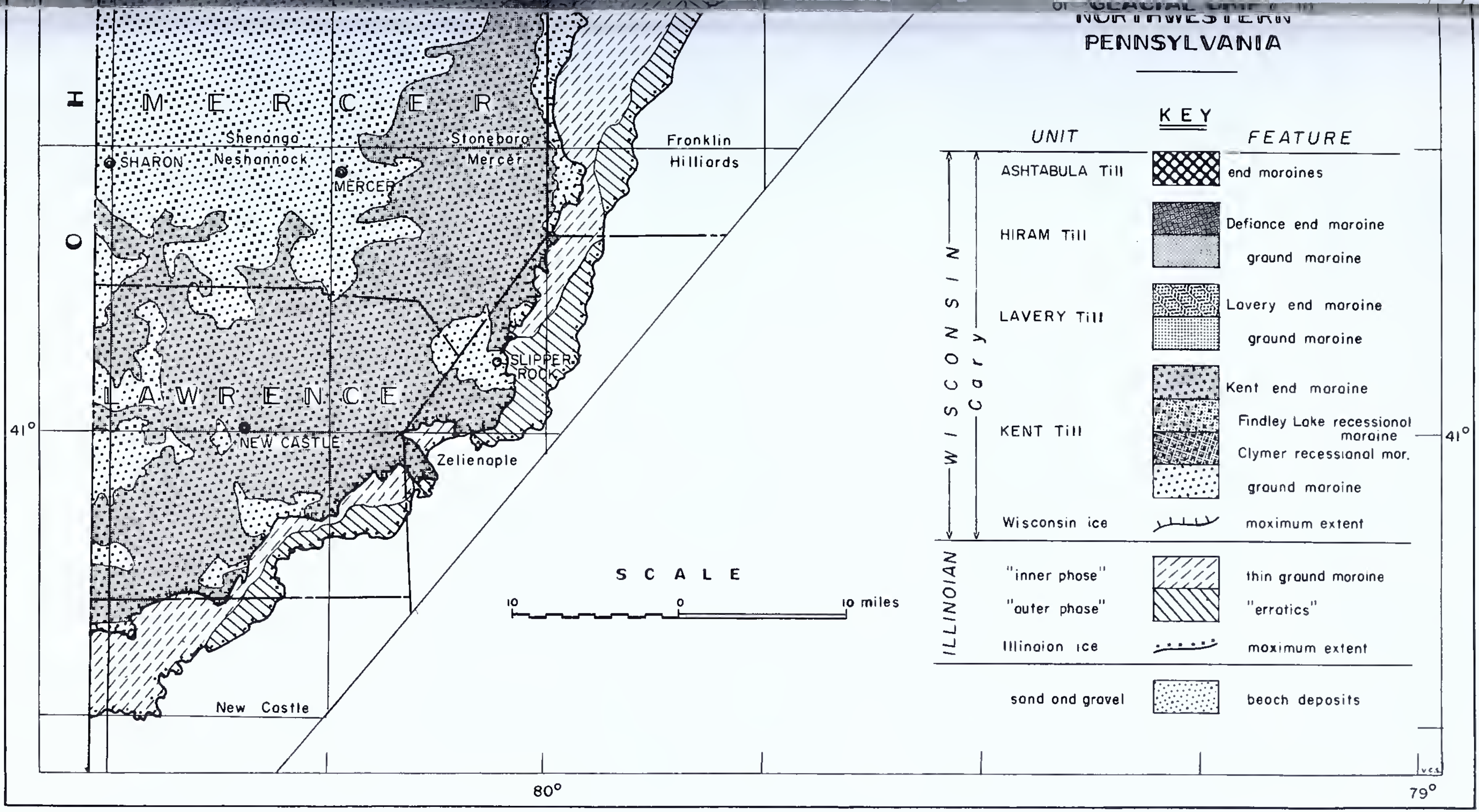

NORTHWESTERN
PENNSYLVANIA
KEY
UNIT
FEATURE
WISCONSIN
Cary
ASHTABULA Till
end moraines
HIRAM Till
Defiance end moraine
ground moraine
LAVERY Till
Lavery end moraine
ground moraine
KENT Till
Kent end moraine
Findley Lake recessional moraine
Clymer recessional mor.
ground moraine
Wisconsin ice
maximum extent
ILLINOIAN
"inner phase"
thin ground moraine
"outer phase"
"erratics"
Illinoian ice
maximum extent
sand and gravel
beach deposits
SCALE
10
0
10 miles
H
O
MERCER
LAWRENCE
Shenango
Neshannock
Stoneboro
Mercer
SHARON
MERCER
Franklin
Hilliards
SLIPPERY ROCK
NEW CASTLE
Zelienaple
New Castle
41°
41°
80°
79°

Figure 4

since none of the factors is a constant. Depth of leaching, for example, can be stated only as an average, for within each till variation in depth of leaching is considerable. For this reason, in the discussion which follows, values for depth of leaching, texture, etc. are given as averages. The reader must realize that actual values will vary in either direction from the stated average. Where information is available, the extent of the variation is given.

Multiple sections, i.e. sections showing more than one till, help to establish the sequence of glaciations and the relationships between the various deposits. They have been used to tie together studies of the till texture (Shepps, 1953, p. 40-42). A number of the measured sections have been recorded by Shepps (1955) and Sitler (1957). Although it is not possible to reproduce all of these sections here, one excellent section, named the Venango section, is most valuable in demonstrating multiple glaciation and the relationships between four of the northwestern Pennsylvania tills and is reproduced below. The Venango section is recorded as Pennsylvania footnote #1 on the glacial map by Flint et al (1959).

THE VENANGO SECTION

The Venango section is located on the west side of French Creek, approximately 1.6 miles along the road south of Venango, Venango Township, Crawford County. The face of a high valley wall has been cleared of overburden by slumping following undercutting at the base to make room for a new road. The face of the section is shown in Figures 5 and 6. The section description which follows was measured along the line shown in Figure 5. For reference the various tills in the section are numbered both in the section description and in the figures.

Description of the Venango section is as follows:

	Unit Thickness		Aggregate Thickness	
Kent (Cary)	Ft.	In.	Ft.	In.
Till (I) with soil profile, brown, loam, moderately pebbly, calcareous in part	15' estimated		15'	
Till (1), same as above but gray, calcareous, lower part streaked with silt, gradational into unit below, thickness of unit variable	15	0	30	0

Venango section, continued	Unit Thickness Ft.	Unit Thickness In.	Aggregate Thickness Ft.	Aggregate Thickness In.
Silt, gray, massive, locally fine-grained sand, calcareous, thickness variable	13	0	43	0
Till (1), gray, loam, moderately pebbly, calcareous, pinches out northward, silt streaks at the top, transitional upward	10	8	53	8
Kent or Tazewell				
Sands and gravelly sands, mottled orange, gray, and brown, calcareous (secondary?), cementation streaks, crossbedded sands occur in depressions in the top of the unit below, thickness fairly persistent	1	9	55	5
Mogadore (Tazewell)				
Till (2), gray, sandy, silty, pebbly, calcareous	14	4	69	9
Tazewell ?				
Silts and clays, gray, mixed and sheared, probably bedded originally, pinch out northward	0	3	70	0
Tazewell or Sangamon				
Bedded silts and sands, brown and orange, possible insipient soil, but not probable	0	3	70	3
Illinoian (inner phase ?)				
Till (3), brown at top, blue-gray at the base, sandy, silty, pebbly, calcareous. Thickness of the upper oxidized brown portion is variable and extends along joints in some places for 2 or 3 feet. Patches of blue-gray till occur within the brown till. Contact between the two colors is always sharp. The thickness of the brown horizon increases northward until the entire unit is brown. Silt or sand lenses occur in the till at some places. Very pebbly toward the base.	5	0	75	3

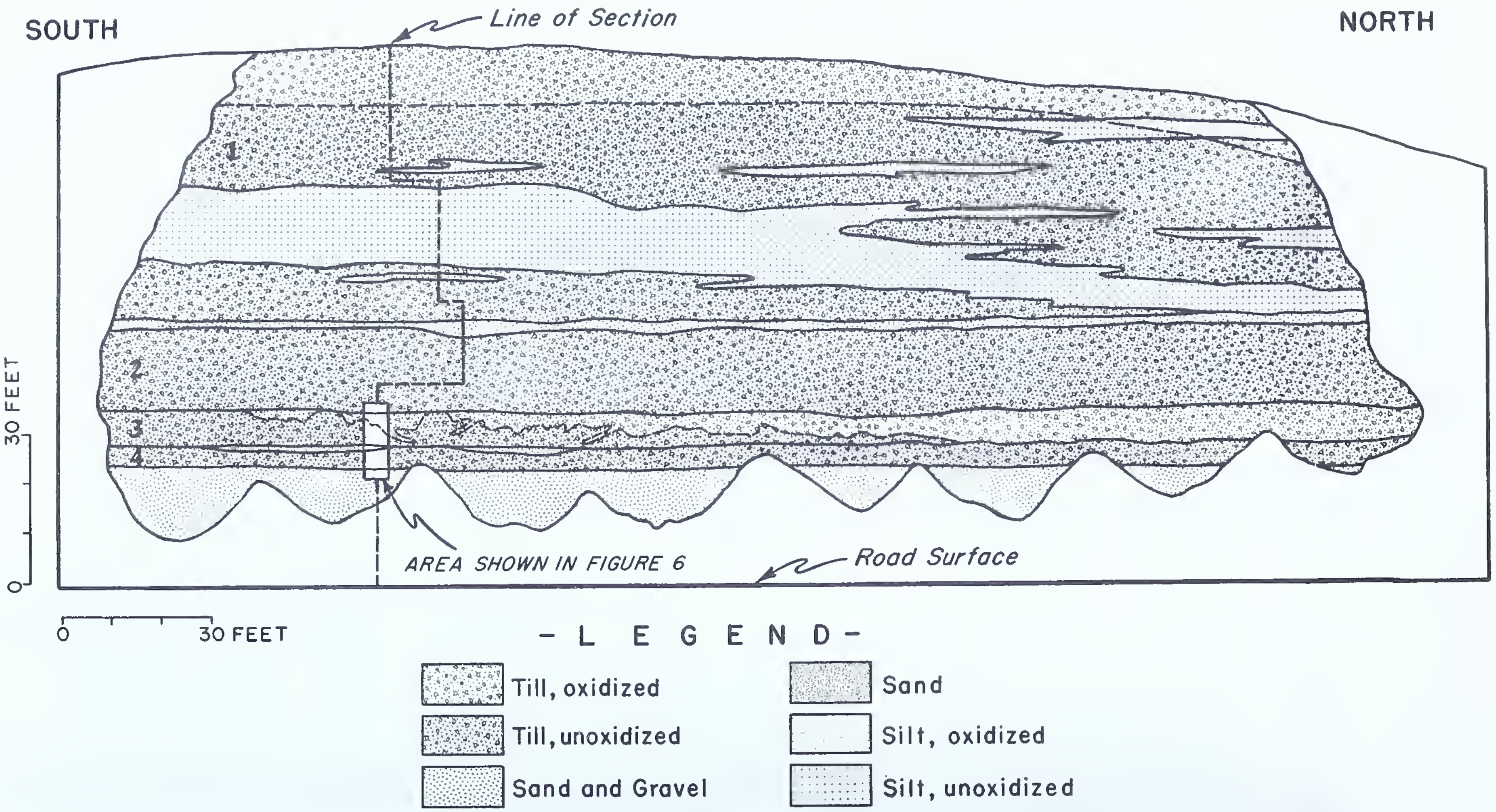


Figure 5. Generalized diagram of the Venango section.

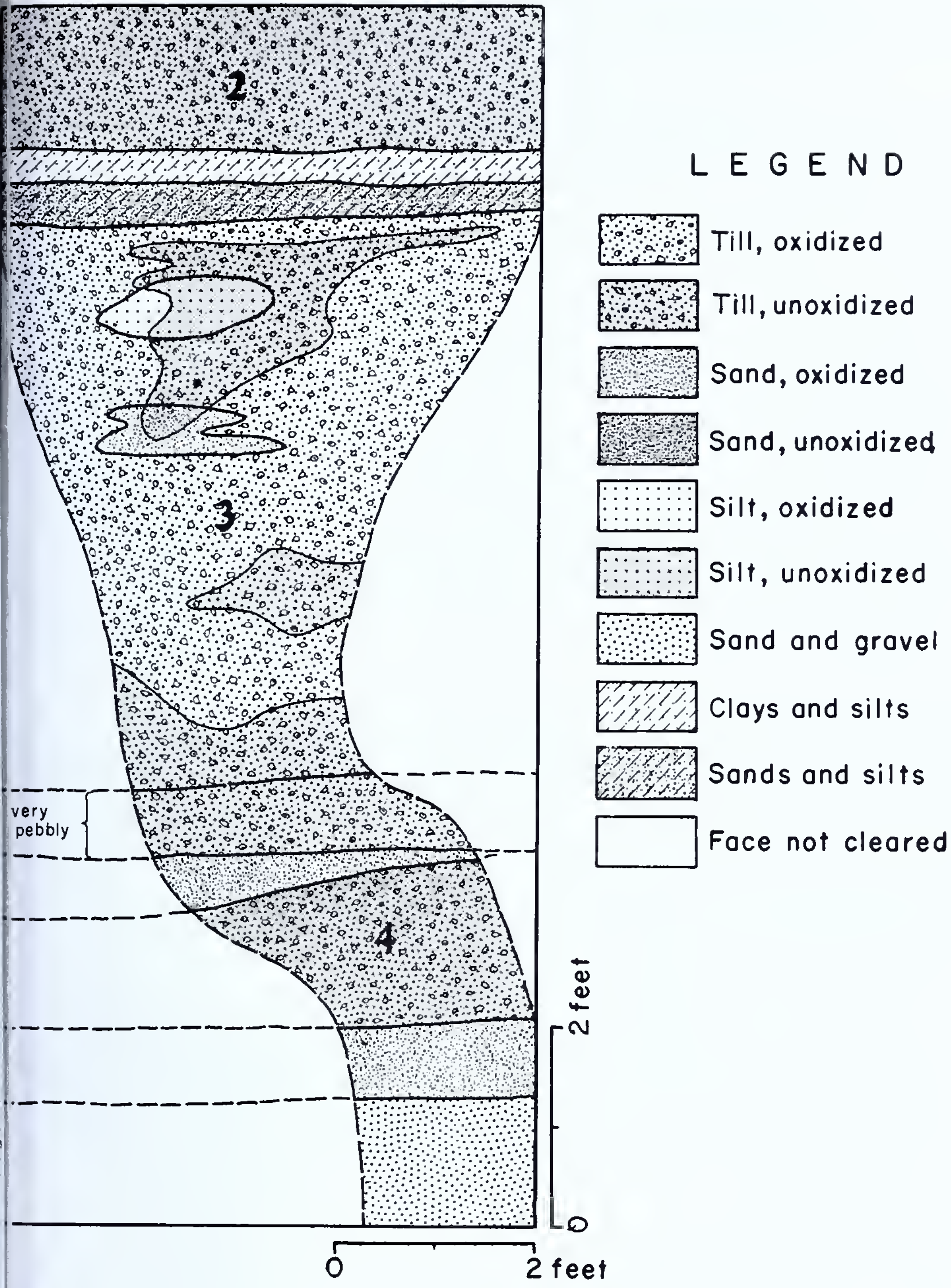


Figure 6. Venango section. Detail of area shown in Figure 5.

Venango section, continued	Unit Thickness Ft.	Unit Thickness In.	Aggregate Thickness Ft.	Aggregate Thickness In.
Sand, fine-grained, brown, calcareous, very variable in thickness, commonly absent	0	5	75	8
Illinoian (outer phase ?)				
Till (4), brown, very sandy, very pebbly, calcareous, thickness somewhat variable	3	6	79	2
Sand, medium-grained, dark-brown, calcareous	2	0	81	2
Gravelly sand, dark-brown, calcareous, thickness given is maximum exposed	8	0	89	2
Cover,variable	12	0	101	2

A detailed discussion of the dating of the various tills is given by Shepps (1955). Only a resumé of this discussion will be given here. The Venango section is located in the area of the Kent ground moraine well south of the Hiram and Lavery borders. For this reaso the top till in the section would be expected to be Kent Till. Evidence from the section itself, e.g. texture and profile characteristics confirms that till 1 is Kent.

The sand and gravel unit between till 1 and till 2 is believed to represent a time break. Though the oxidation of this unit may hav resulted from groundwater activity, its uniformity both in thickness and extent, the apparent lack of primary carbonates, and the lack of washing in the upper parts of till 2 suggest that the sand and gravel was not deposited in association with the till. Rather it appears that the top of till 2 was leveled and eroded so that there were shallow channelways on its surface when the sand and gravel was deposited. In addition, the fact that till 2 is texturally different from till 1 and similar to near-by Mogadore Till supports the conclusion that till 2 i Tazewell Mogadore Till.

The most definite and significant time break in the section is the weathering interval represented by the oxidation of the top of till 3. The depth of oxidation of till 3 is at least five feet since the entire section is oxidized at the north end of the cut. The profile everywher the section is truncated to an unknown depth because nowhere are e upper soil horizons, the horizons of decomposition, preserved. he time interval indicated by this weathering is too great for any of e Wisconsin interstadial periods and most likely represents Sanga- on time. Till 3 is consequently pre-Sangamon and most likely is ner phase Illinoian. The till is texturally coarser than the usual ner phase till but little is known of the possible variation in texture the inner phase till. Texturally till 3 is similar to the outer phase inoian till and for this reason could be outer phase Illinoian. The cess of pebbles in the basal part of till 3 may be the result of the xing of very pebbly till 4 with till 3.

Till 4 is distinctly different from till 3. It is also coarser in xture than any of the tills seen elsewhere in northwestern Pennsyl- nia. However, since little is known of the texture of the outer phase inoian till, the coarseness of the texture does not rule out the possi- ity that till 4 is outer phase till. No weathering interval is present tween till 3 and till 4 to suggest that the latter till may be earlier n Illinoian, and since no earlier glaciations are known for Pennsyl- nia it is assumed that till 4 is most likely Illinoian material. If so, is probably outer phase till. The dark-brown color may be inferred indicate oxidation, but is more likely the original color of the till.

The Venango section, in summary, is believed to contain Kent ll, over Mogadore Till, over inner phase Illinoian till with a Sanga- n profile, over outer phase Illinoian till.

DEPOSITS OF THE NEBRASKAN STAGE

No deposits of Nebraskan age have been found in northwestern nnsylvania. Evidence to indicate that Nebraskan ice ever entered area would be in the form of drainage diversions or high outwash race remnants. Studies of the subsurface and of the high terraces ve not been sufficiently detailed to distinguish such evidence. Pre- noian glaciation has been postulated for northeastern Ohio by White 34) and by Winslow (1957) based upon drainage diversions.

AFTONIAN INTERGLACIAL DEPOSITS

Deposits formed in the interval between Nebraskan and Kansan ne (the Aftonian Interglacial Period) are not known in northwestern nnsylvania. Winslow (1957) has recognized Aftonian and later drain- systems in buried channels in eastern Ohio.

Deposits of the Kansan Stage

Drift of supposed Kansan age was reported in northwestern Pennsylvania by Leverett (1902, p. 228-252). Leverett later presented a map and a discussion of what he then called "pre-Illinoian" deposits (Leverett, 1934, Pl. 1 and p. 94-100). Leverett's "Kansan" and "pre-Illinoian" deposits are now interpreted as either colluvium, Illinoian outwash, or other non-ice deposits. The area mapped by Leverett (1934, Pl. 1) as pre-Illinoian has no till, and no erratics were found in it in the present investigation. Proof of the existence of Kansan outwash terraces on which Leverett established Kansan glaciation must await detailed studies which can now be based upon detailed knowledge of the drift sheets.

Yarmouth Interglacial Deposits

Deposits formed during the Yarmouth Interglacial Period are unknown in northwestern Pennsylvania.

Deposits of the Illinoian Stage

Deposits of Illinoian materials are found in a 1 to 15 mile wide belt along the border of the glaciated area as shown in Figure 4 and in Plate 1. Two subdivisions of the belt are recognized - an outer belt where till is rare and an inner belt where thin till is normally present These are identified as an outer and an inner phase of the Illinoian glaciation and are considered to represent two advances of the Illinoian ic The outer phase, nearest to the glacial border, represents the first advance and the inner phase represents the later advance.

OUTER PHASE

Topography within the outer phase area is almost entirely erosional and similar to that on the land surface outside of the glacial border. The hills, however, are less rugged and appear more rounde than those outside of the border. Although some soils in this area are developed on bedrock, the influence of the Illinoian till is still apparen in detailed soil studies (Bacon and others, 1954, p. 13, 30, 46, 49, and map).

Deposits of material within the area mapped as outer phase Illinoian consist of erratics most of which are quartzites, and very rare patches of thin till and oxidized gravels. The tills are usually highly weathered such that their original character cannot be defined. In strip mine sections near Slippery Rock, Sitler (1957, p. 30-35) found the outer phase till buried beneath inner phase till and/or

Wisconsin till. In these sections the character of the outer phase till a be defined as being a dark-olive-gray, very weakly calcareous, nderately pebbly, sandy, clayey till. This outer phase Illinoian is c Leverett's Kansan (1934), but is part of what he also called Ilnoian.

INNER PHASE

The inner phase Illinoian area generally displays an erosional ography essentially the same as that on the outer phase area although ne small areas of greatly modified constructional topography are to found. The area appears to have been covered by ground moraine, the existence of some kames along the outer border suggests that a ak end moraine may have existed. The soils in the inner phase area e been developed almost entirely upon glacial materials (Bacon et al, 4).

Deposits in the inner phase area include a fairly continuous, thin blanket (5 - 10 feet thick) and scattered subdued kames and kame erraces. The till is rarely thick enough to show unleached materials ept in buried valleys where the materials are seldom exposed. One h case is described by Droste and Tharin (1958, p. 62) and several posures of the inner phase till were reported by Sitler (1957, p.30-35). ese exposures show the inner phase till to be finer grained than the er phase till. The till is a light-olive-gray to light-gray, moderately sparingly pebbly, weakly calcareous, silt to clayey silt till. The till rmally has a horizontal parting and often shows heavy manganese ining of joint surfaces in the upper part of the "C" horizon (horizon 3 Leighton and MacClintock, 1930). Horizon 4 is commonly very thin missing. This till is a continuation of that well shown in Columbiana unty, Ohio (White, 1951 a).

GLACIOFLUVIAL DEPOSITS

Illinoian kames and kame terraces exist as shown on Plate 1. deposits recognizable as glaciofluvial were found in the inner phase ea. Good displays of kames occur in and around Franklin and Warren, d kames as well as kame terraces occur at Titusville.

Outwash terraces were not mapped in detail, but are known to ist in a position not much higher in altitude than the highest Wiscon- n terraces. More detailed work is required to define the limits and e ages of the terraces which exist along most of the rivers heading or ssing through the glaciated areas. Only the most obvious terraces e shown on the map (Pl. 1) and these have not been precisely delim- d.

Sangamon Interglacial Deposits

No deposits of Sangamon age material have been found such as those found at Cleveland (White, 1953; Leonard, 1953). Evidence of weathering during this interglacial period is found in the form of truncated profiles (Shepps, 1953, p. 47-52 and Sitler, 1957, p. 27-35). Sections in the area where Illinoian materials are at the surface have shown in some places a reddish profile of weathering on Illinoian till buried beneath later colluvium. The profile in this case need not be Sangamon, but could have formed at any post-Illinoian time up to the time that the colluvium covered the section.

More intense searching may uncover sections of Sangamon deposits or of thicker weathering profiles, particularly in the areas where strip mining for coal is continually making new exposures.

Deposits of the Wisconsin Stage

GENERAL STATEMENT

Ice advanced into northwestern Pennsylvania five times during the Wisconsin Age of the Pleistocene Epoch. Advances occurred at least once during the Tazewell Substage and four times during the Cary Substage as a lateral expansion of the Grand River Lobe (Fig. 2), except the last which was an expansion of the Erie Lobe only. The ma imum extension of each Cary advance is shown in Figure 4 and in detai in Plate 1. The limits of the Tazewell ice do not show in Figure 4 and Plate 1 since the marginal Tazewell ice was overridden by the first Cary advance.

The advance during the Tazewell substage is named the Mogadore advance from the till it deposited near Mogadore, a suburb of Akron, Ohio (White, in press). Cary advances have been given local names from oldest to youngest as the Kent, Lavery, Hiram, and Ashtabula advances from the till deposited in each advance (White, in press) Advances of ice of other substages did not reach Pennsylvania. Evidence that Farmdale ice advanced to a point north of Cleveland has bee found by White (1953 a, p. 36-38), but no evidence has been found that this ice entered Pennsylvania or that any Farmdale age material has been deposited in Pennsylvania. Deposits of post-Cary age are presen in the form of beach and lake deposits laid down by former higher level lakes in the Erie Basin.

Investigations in Ontario by Dreimanis (1958) indicates that onl one till was deposited in the Toronto area as a representative of the time interval from Farmdale to Mankato. This means that the Toronto area was covered by ice continuously while five tills were being deposite in northwestern Pennsylvania and that the ice between the advances wich deposited these tills never retreated as far north as Toronto. Tis indicates that the advances of ice into Pennsylvania were fluctuatins of the front of a major ice mass which never completely disapeared during Farmdale to Mankato time. It further suggests that th periods between ice advances were short-lived, an hypothesis which sems tenable for the breaks between the Cary advances; the interval btween the Tazewell and the Cary advances would more generally have ben thought to be of sufficient length that the ice would have retreated pst Toronto.

TEXTURAL STUDIES

Samples of unweathered till were collected during field work wenever such material was exposed. Size analyses were made of these samples using the methods of Shepps (1953). The results of part o these studies of Pennsylvania tills have been published (White and Sepps, 1952; Shepps, 1953, 1955, 1958; Sitler and Chapman, 1955; Sler, 1957; Droste, 1956 a, b; Droste and Tharin, 1958; White et al, 157). All of the size analyses of Pennsylvania samples were evaluaed by J. C. Tharin (1958) and are presented here with minor changes i Figures 7, 8, 9, and 10 to facilitate discussion of the texture of the tils.

As a means of comparing and analysing till texture, a method o graphical presentation has been devised by Shepps (1958). Using this mthod, each analysis is plotted on a rectangular graph which has been sbdivided diagonally into size classes which are assigned arbitrary nmbers called size factors (Fig. 7). The number of samples in each sze class is totaled (frequency) and the information is then plotted in te form of a histogram of frequency against size. The reader may be aled in understanding discussions of texture involving size factors if h will observe that the larger the size factor, the coarser is the textre. A sandy till, for example will have a size factor of 27 or 28 compred to a clay till which will have a value around 12 or 13. Size factrs may be translated to approximate mean size by reference to a cart constructed by Shepps (1958).

The analyses of 242 samples of Wisconsin till from northwesten Pennsylvania are presented on a rectangular graph in Figure 7. he number of samples collected for each age till is roughly proportonal to the outcrop area of the till and is as follows – Mogadore, samples; Kent, 147 samples; Lavery, 30 samples; Hiram, 22 smples; and Ashtabula, 28 samples. The analyses measure the atrix of the till only. The matrix is defined as the material in the smple finer in size than 4mm which includes sand (4mm to .062mm), lt (.062mm to .0039mm), and clay (less than .0039mm). In Figure 7 e size class boundaries have been drawn and sample frequencies for ch age till have been totaled and are listed for each size class.

The data of Figure 7 are presented in Figures 8, 9, and 10 in the form of histograms. Figure 8 shows a histogram for each of the Wisconsin tills. These are plotted together, with the exception of the Ashtabula Till, for purposes of comparison. The Ashtabula samples have been separated only to avoid confusion. Figure 9 shows the distribution of texture of the Kent Till within separate areas (shown on Pl. 1) in northwestern Pennsylvania. In Figure 10 the tills of Pennsylvania are compared with the same tills in northeastern Ohio.

Discussions of the texture of each of the tills is reserved for the sections dealing with the individual advances. The figures cited above will be referred to in these sections. With the knowledge of texture gained by size analysis, it is possible in northwestern Pennsylvania to use texture as an additional tool to aid in identifying and correlating the various tills.

In describing tills in the text the authors use clay, silt, loam, etc. to modify till, for example clay till, silt till, etc. It is to be understood that these terms may be freely interchanged with clayey, silty, loamy, etc. and that they are being used to describe texture only and are not intended to define a new material. The terms, moreover, are chosen to describe the apparent texture of the tills in the field. A till which, in the field, appears to have equal amounts of sand, silt, and clay is called a loam till. If silt obviously predominates it is called a silt till. Because of this, the terms do not necessarily indicate the laboratory analysis of the texture. This is obvious when the terms which have been applied to the various tills are compared with the analyses of the same tills. This is largely a consequence of the fact that the average worker tends to overestimate the amount of clay in a sample at field moisture conditions.

DEPOSITS OF THE TAZEWELL SUBSTAGE

GENERAL STATEMENT

Tazewell ice advanced into northwestern Pennsylvania to deposit Mogadore Till in a position behind the maximum extent of the later Cary ice. Full extent of the Mogadore advance is unknown except that it was completely outridden by the next later advance (Kent). Evidenc seems to indicate that only one advance occurred during Tazewell tim but the scarcity of pre-Cary exposures leaves this open to question. White has found only one drift of Tazewell age in Ohio (White, 1953, p. 18). The Mogadore drift of Pennsylvania has been traced beneath Cary (Kent) drift from the type area at Mogadore near Akron, Ohio where it crops out. This till is called Tazewell on earlier maps (White, 1953 d, Pl. 26).

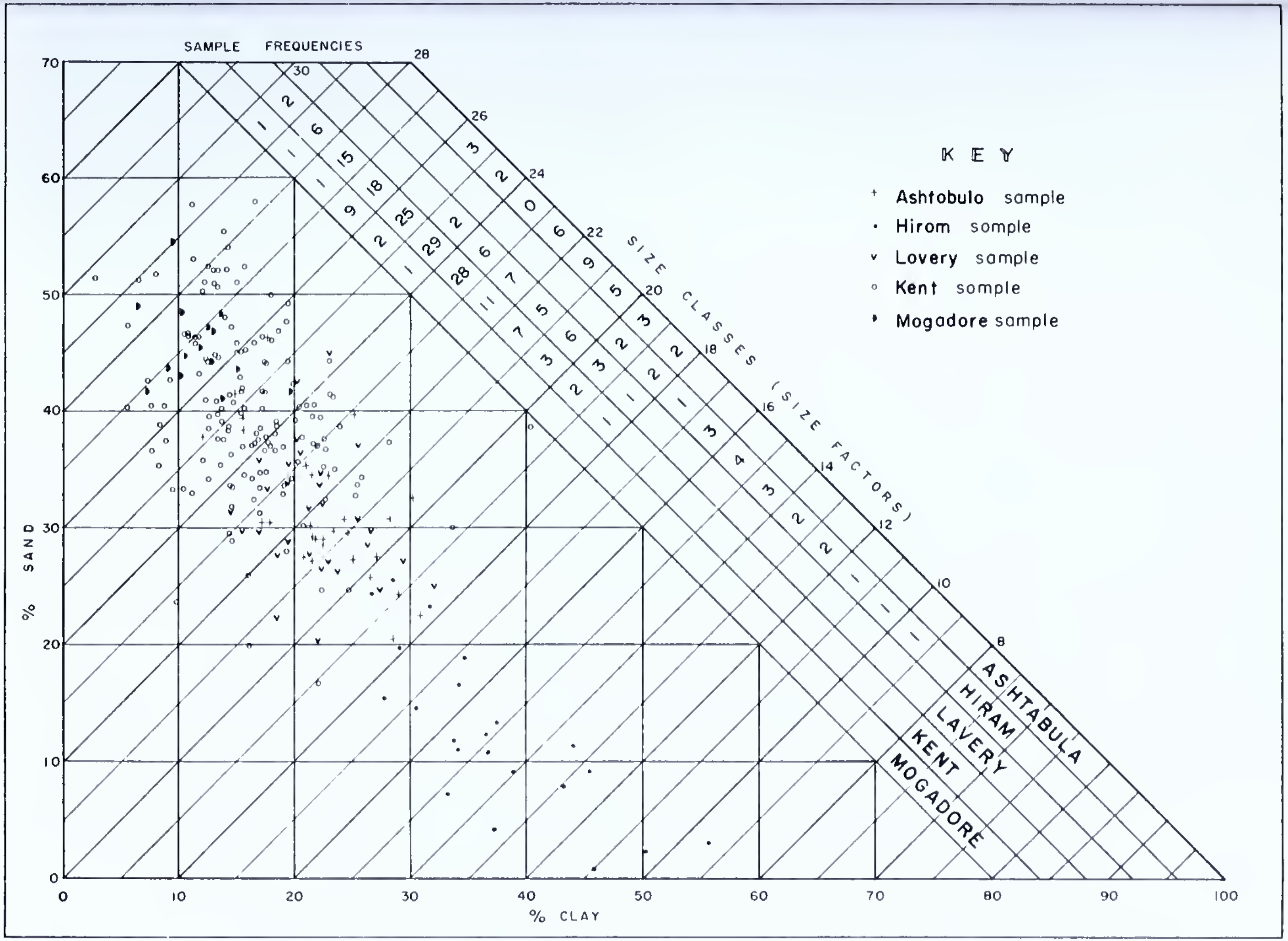


Figure 7. Rectangular graph showing textural analyses of Wisconsin age tills from northwestern Pennsylvania.

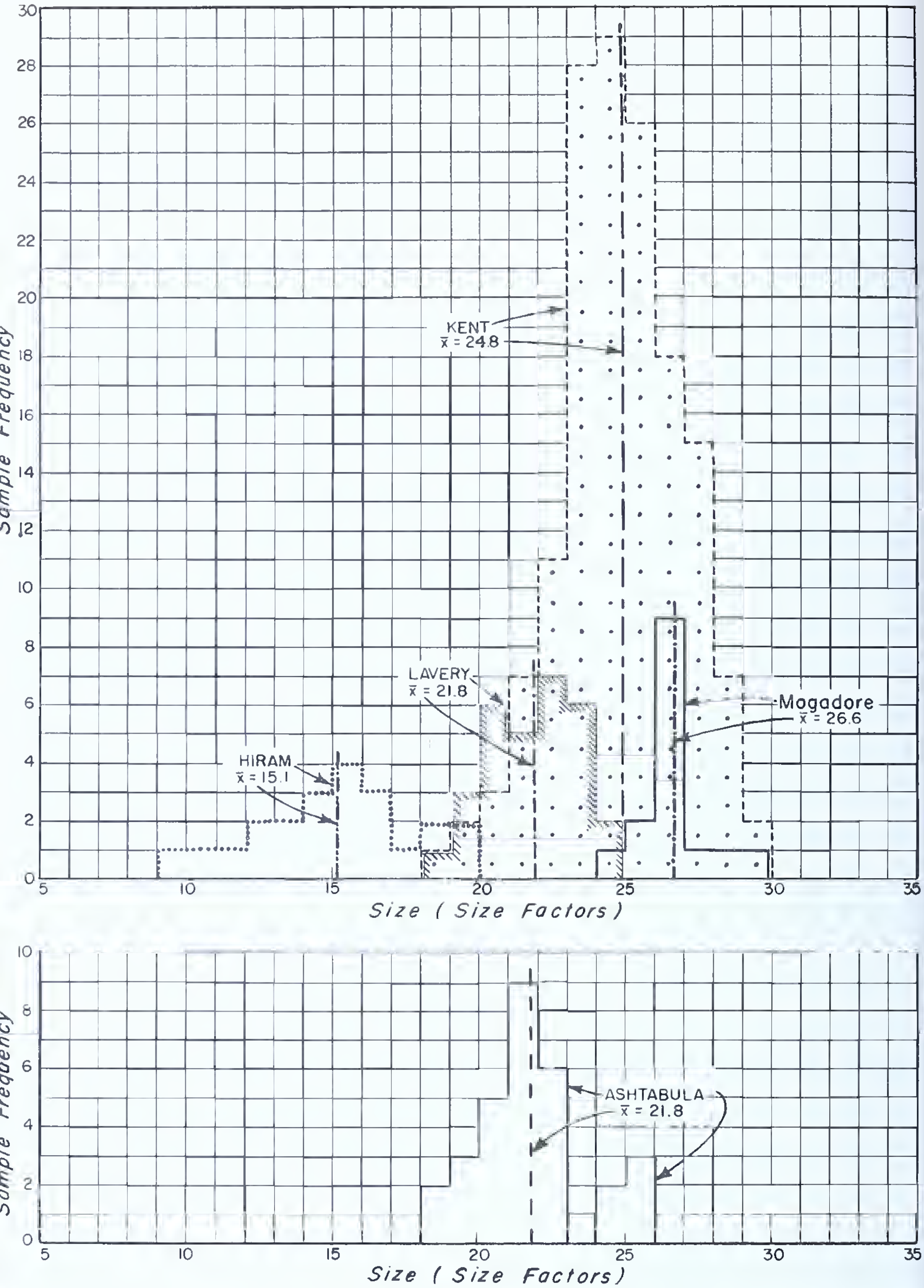


Figure 8. Histograms showing the distribution of texture in the Wisconsin age tills from northwestern Pennsylvania.

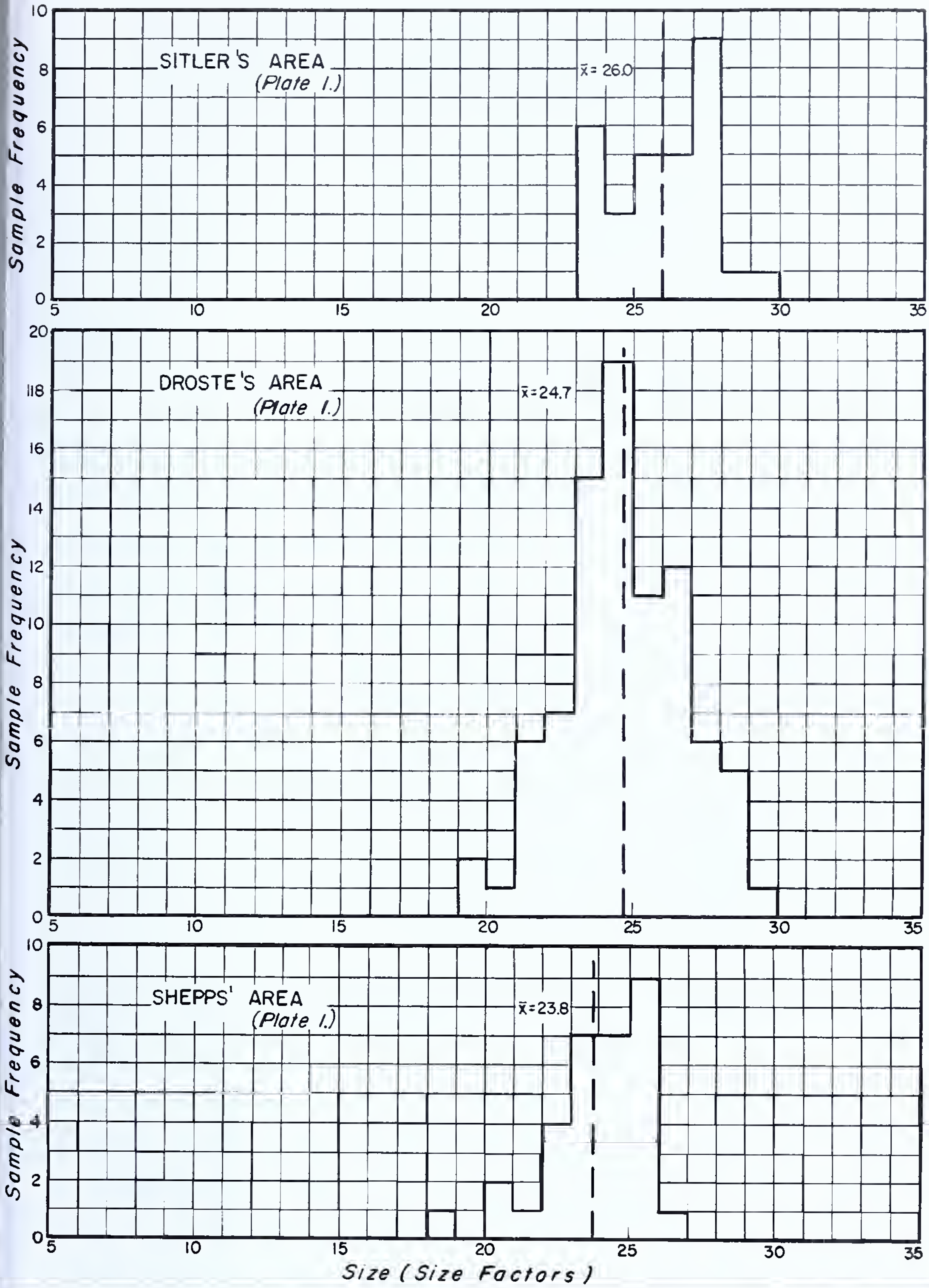


Figure 9. Histograms showing the distribution of texture in the Kent till in various parts of northwestern Pennsylvania.

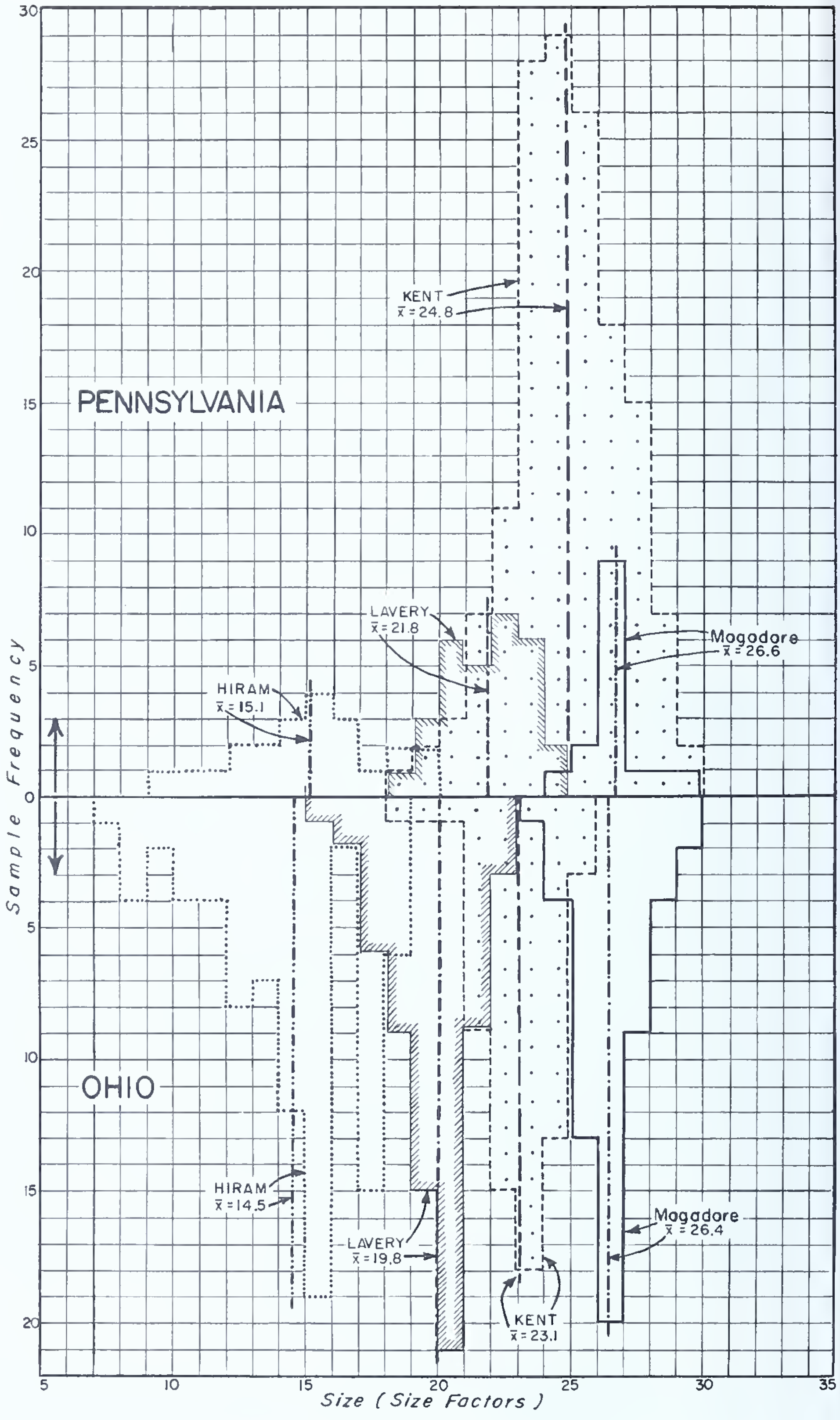


Figure 10. Comparison of the Pennsylvania and Ohio tills.

Mogadore Till was found at a number of places buried beneath later Cary drift. Unweathered, unoxidized, Mogadore Till is persistently a gray to bluish-gray, weakly calcareous, moderately pebbly to pebbly, sandy till. The average Mogadore Till contains 46.30% sand, 43.20% silt, and 10.50% clay (Tharin, 1958, p. 31). The till has a limited range of textures as shown in Figures 7 and 8 and is very similar to its counterpart in Ohio as shown in Figure 10. Depth of leaching measurements are not available because the till is always overlain by later materials in Pennsylvania

END MORAINE

No Mogadore end moraine has been discovered to date. If one was deposited it would now be buried beneath later Cary drift and would have been removed or subdued by the overriding Kent ice. No deposits of Mogadore drift have been found in the area of the Kent Moraine, although numerous sections of till over bedrock have been observed. It consequently appears that the Mogadore ice did not advance as far as the Kent end moraine and that an end moraine, if present, is not compounded with the Kent moraine.

GROUND MORAINE

Exposures of ground moraine were found at a number of places in western Crawford and northwestern Mercer County. The till was probably deposited in these areas as a nearly continuous blanket which was thicker in the valleys than on the uplands. Subsequent erosion by overriding ice has altered the blanket so that it is now discontinuous. The thickest deposits of buried Mogadore Till occur in west-central Mercer County where the till exceeds 20 feet in thickness locally. In the areas north of the Lavery and Defiance margins the Mogadore Till appears to be absent. In the Lavery and Hiram ground moraine areas no Mogadore Till was seen although till resting on bedrock was seen in a number of places. In these areas it appears that the Mogadore Till was not deposited as a thick blanket probably because of the smooth, north-sloping topography. For this same reason the till that was deposited would have been easily removed by overriding ice. No deposits of recognizable Mogadore materials were found south of Sharon or east of Meadville. The failure to find Mogadore Till east of Meadville may be attributed in part to the lack of exposures so that the border of the Tazewell advance may be between Meadville and the border of the Kent advance. (Note: Deposits of gravel and gravelly till near the Wisconsin border at Darlington and New Galilee are apparently anomalous in their relation to either Illinoian or Cary drift. They cannot be traced northward to the extensive area of Mogadore Till. The small area of the material, its poor exposure and the inability so far to trace it to the north below Cary deposits makes its interpretation hazardous and for the present it is left undated. It is hoped that future exposures will allow more detailed study so that the material can be shown to be an unusual form of Cary drift, of Illinoian drift, or neither, and an entirely separate deposit. Mention is made here of this materia for the benefit of others who may work in the area).

GLACIOFLUVIAL DEPOSITS

No Tazewell glaciofluvial deposits were found in Pennsylvania although such deposits undoubtedly exist, especially in buried valleys. Such deposits have been found in Ohio where Tazewell materials are exposed at the surface (White, 1953 a, p. 19).

Deposits of the Tazewell - Cary Interstadial Period

At some places in buried sections a periglacial rubble is developed on the top of the Mogadore Till. This rubble, formed during the Tazewell-Cary interstadial period, is characteristically a porous, open-textured, sandy or silty material containing numerous pebbles. Platy fragments have been moved and are commonly oriented parallel to the topography. Fine-grained materials have also been moved and are redeposited as coatings on grains and on the walls of voids. This rubble indicates that a distinct period of weathering and frost action existed between the retreat of the Tazewell ice and the overriding of the next Cary ice. Oxidation of the upper part of the Mogadore Till is found at some localities, but because the Cary till above is oxidized to the base the Tazewell oxidation cannot be attributed with certainty to Tazewell-Cary interstadial weathering.

Deposits of the Cary Substage

GENERAL STATEMENT

Deposits laid down by Cary ice mantle most of the surface of northwestern Pennsylvania as shown in Plate 1 and Figure 4. Roughly two-thirds of the surface is underlain by a till blanket laid down by the first Cary advance, the border of which in two places advanced slightly farther than did the earlier Illinoian ice. This advance is called the Kent advance and occurred during early Cary time. The Kent ice deposited, in addition to the till blanket, a rather bold and continuous end moraine and extensive glaciofluvial deposits. During the retreat of this ice minor readvances occurred which built two somewhat discontinuous recessional moraines – the first called the Clymer Moraine and the second called the Findley Lake Moraine.

Three other later ice advances moved into northwestern Pennsylvania during the Cary Substage, but having less vigor than the Kent ice stopped many miles behind the Kent border. The first of these occurred in about the middle of the substage and has been called the Lavery advance. This was followed after a short time interval by another advance named the Hiram advance. Both the Lavery and the Hiram advances are recorded by subdued end moraines and thin ground moraines. The last advance of Cary time occurred near the close of the substage when ice moved down the Erie Basin and by minor readvances during retreat laid down a series of en echelon end moraines parallel to Lake Erie. This final advance is named the Ashtabula advance. As noted earlier, ice between the Cary advances did not retreat far into Canada. It did, however, retreat from Pennsylvania and probably out of the Erie Basin.

KENT ADVANCE

General Statement

The Kent advance was the earliest advance of Cary ice into northwestern Pennsylvania. It is thought to have occurred during early Cary time, but may not be equivalent to the earliest Cary advance in other areas. The till of this advance has been given the local name of Kent by G. W. White (in press) in Ohio. The type area for the unit is in and around the City of Kent in Portage County, Ohio where the Kent till is well exposed and where the Kent end moraine is well developed. The Kent Moraine and Kent drift as mapped in Pennsylvania are correlated with the same units at the type area in Ohio by direct field tracing supplemented by laboratory evidence. In Pennsylvania the Kent drift rests unconformably upon drift of Tazewell or Illinoian age, or upon bedrock.

Deposits of Kent drift in Pennsylvania include till in the form of end or recessional moraine and ground moraine; and washed materials deposited as kames, kame terraces, crevasse fillings or eskers. In addition, valley train outwash deposits are found in most of the major valleys south of the end and recessional moraines. Extensive development of kames and kame terraces is a feature of the Kent episode.

The Kent Till where fresh and unweathered is a bluish-gray, moderately pebbly to pebbly, calcareous, loam to sandy loam till. It is yellow-brown where oxidized. Sandy loam till exists largely in the Kent Moraine in Mercer, Lawrence, and Butler counties; and to a lesser degree in the remainder of the Kent Moraine and in the recessional moraines. The ground moraine, in general, is a loam till. The texture of the Kent Till, if considered for the whole area, appears to be quite variable. The variation is more limited if smaller areas are considered, because the till gradually becomes coarser toward the south. For the area as a whole the average textural composition is 40.55% sand, 43.33% silt, and 16.12% clay (Tharin, 1958, p. 31). The average texture in terms of size factors is 24.8 and the textural range is from 18 to 30 size factors (Figs. 7 and 8). Though the variation of 12 size factors appears to be large, it should be noted that 87% of the samples fall within 5 size factors (23 to 27).

The smaller variation within limited areas is demonstrated in Figure 9 which shows histograms of the Kent tills within each of the areas of study (Pl. 1, index map). In the area mapped by Shepps the till averages 23.8 size factors and has a range from 18 to 27 size factors. In the area mapped by Droste the till averages 24.7 size factors and ranges from 19 to 30. Till in Sitler's area averages 26.0 size factors and ranges from 23 to 30. From these values it appears that the Kent Till is coarsest in the south, finest in the northwest and intermediate but variable in the east. Sitler has shown that the Kent Till in the southern counties becomes gradually coarser toward the Kent border by plotting and contouring sand/silt ratio values for the till (Sitler, 1957, p. 49). The same appears to be true along all of the Kent border, although it was possible to collect fewer samples from the border areas and the Kent Moraine northeast of Sitler's area. Nevertheless, this tendency for the till to become coarser toward the border accounts in part for the large variation in texture of the Kent Till in Droste's area. The Kent Till in Ohio averages 23.1 size factors and consequently is finer than the Pennsylvania Kent Till. There appears to be a slight, but gradual increase in size eastward from Ohio.

The depth of leaching of the Kent Till in the ground moraine averages 70 inches with measured variation from 63 to 120 inches. Values above 100 inches are probably abnormal and indicate the presence in the section of non-till material inter-stratified with the till. In the Kent Moraine the depth of leaching increases to an average depth near 100 inches. Maximum variation within these areas is unknown, but is large. The increase can be attributed in part to the decrease in fines and to better drainage conditions in the end moraine.

Kent Moraine

The end moraine of the Kent advance extends diagonally across northwestern Pennsylvania from Warren County to Beaver County as shown in Figure 4 and on Plate 1. This is the main terminal moraine of H. C. Lewis (1884) and Chamberlin (1890). The moraine trends from Warren County through Crawford and Venango counties and into northeastern Mercer County as a three-to four-mile-wide band broken only by crosscutting valleys. Shortly after entering Mercer County the moraine becomes broad, discontinuous, and is interspersed with patches of ground moraine.

The surface of the Kent Moraine exhibits a boldly constructional knobby topography in contrast to the flatter, smooth topography of the ground moraine or to the erosional topography of the Illinoian areas. The Kent Moraine does not mark the outer boundary of the advance except in a few places. In most places a band of thin ground moraine exists between the border of the advance and the front of the Kent Moraine. Numerous undrained depressions including several rather large swampy areas occur within the moraine especially where it is broad.

The materials making up the Kent Moraine include the Kent Till which varies in texture from loam to sandy loam till, and sand and gravel. In places the Kent Moraine is composed of kames rather than true till mounds. These are indistinguishable from the true till areas except on the basis of the contained material and they are genetically closely related to the moraine. The areas containing sand and gravel have been mapped separately wherever possible and are called hereafter morainal kames. Morainal kames consist of sand and gravel with some silt and clay, and with some interbedded masses of till. The till areas seldom contain only till but contain sand and gravel as stringers, beds, or masses and in some cases are transitional into morainal kames. It is difficult in some cases to draw a boundary between the till and the sand and gravel. Information on thickness of the material in the Kent Moraine is not abundant, but thickness of 50 to 75 feet are common in Mercer County and are probably representative for the Kent Moraine throughout Mercer County and the area to the south. Thicknesses in valley bottoms and in places where the Kent Moraine has buried an earlier valley are greater than 75 feet, commonly around 100 to 150 feet, and are known in some places to exceed 200 feet. North of Mercer County thicknesses in the Kent Moraine are probably less than to the south and seldom exceed 50 or 60 feet.

Clymer and Findley Lake recessional moraines

During the retreat of the Kent ice there were minor readvances of the ice resulting in the formation of two discontinuous recessional moraines behind the Kent Moraine. Both of these are best formed in New York State and will be named for localities in that state by E. H. Muller (personal communication). Both moraines in Pennsylvania were mapped by Leverett as part of what he called the inner and outer Cleveland moraines. (Leverett, 1902, Pl. XV).

The first to be formed was the Clymer Moraine named for the town of Clymer, New York where the moraine is well developed. This moraine in Pennsylvania is represented by two patches of strongly hummocky, constructional topography much like the Kent Moraine (Pl. 1). The second formed moraine is named the Findley Lake Moraine after Findley Lake in New York State. The moraine forms a continuous mile-wide band paralleling Lake Erie (Pl. 1). The till the two recessional moraines is similar to the till in the adjacent ound moraine. Size analyses of the till from these two moraines too few to allow exact descriptions of texture.

ound moraine

Approximately half of northwestern Pennsylvania is covered at surface by Kent ground moraine. The ground moraine forms a arly continuous blanket covering uplands, slopes, and valley bottoms. ift on the uplands in the Kent ground moraine averages 10 to 20 feet thickness. It is seldom thicker than 20 feet except in valley bottoms in areas where a former valley has been buried and filled. At ces, especially on steep slopes, the Kent drift is absent so that the ft at the surface may be Tazewell. Bedrock commonly crops out on ep valley walls or along small tributary streams which run perpen-ular to the main valleys and cut into the valley walls.

The surface on the ground moraine is smooth, nonconstructional, l is, in general, without undrained depressions. Constructional top-raphy in the ground moraine area invariably indicates the presence kames, kame terraces or other such features; or reflects the pres-ce of thinly covered bedrock knobs such as Quarry Hill just south-st of Greenville.

The drift composing the ground moraine consists of Kent loam with some interstratified washed materials. Interstratified mate-ls do not appear to constitute a large part of the drift in spite of the t that a great amount of water activity is indicated by the abundance Kent glaciofluvial deposits. Numerous sections of Kent Till have en observed to be free of non-till materials. Non-till materials inter-dded with Kent Till are seen mostly in sections immediately adjacent valleys.

mes, kame terraces, crevasse fillings, and eskers

As noted above, deposition of glaciofluvial material by the Kent was so extensive that it can be said to characterize the advance. rdly a valley wall within the area of Kent ground moraine is without lisplay of knobby kames or kame terraces. Boldly constructional mes and kame terraces are so well displayed and are so continuous ng some of the valleys that Leverett was led to call them an outer eveland Moraine (Leverett, 1902, p. 620-625 and Pl. XV opposite 436). Eskers, crevasse fillings, and morainal kames make up a derately large portion of the Kent Moraine in the southern counties.

Kames, kame terraces, and eskers consist largely of sand and avel with minor amounts of interbedded silt and clay. Masses of till common to kames elsewhere are not markedly conspicuous in the kame of northwestern Pennsylvania. Such till masses, where seen, are com posed of loam till similar to that of the near-by ground or end moraine. Many of these deposits have been opened as sources of sand, sand and gravel, or fill material. Depth of leaching was never observed to be less than nine feet in these features and varies normally between 9 and 15 feet. Depth of oxidation is generally deeper than the depth of leaching, but in many exposures of Kent glaciofluvial materials the two are the same.

Kame terraces with "flat tops" are rare and features composed of a series of kames in a row along a valley wall are here called kame terraces to distinguish them from isolated mounds or "kame fields" which show no lineation. These features are all thought to have formed after stagnation and during decay of the ice sheet by deposition from meltwaters flowing into and through widening fractures or crevasses in the ice, or between ice masses in the valleys and the adjacent valley walls. Kame and kame terrace deposits are in the form of irregularly-placed, knobby mounds containing a diversity of materials which are crossbedded in various directions. Eskers, on the other hand, are better sorted than kames and show crossbedding generally in one direction suggesting that there was distinct stream flow along a channel. The channel in which the eskers formed may or may not have been open to the surface. Not uncommonly eskers begin at a kame or kame field.

Since these features have not been separated on the map (Pl. 1) it is not possible for the reader to identify the various types. Although not separated from the other features, eskers can be identified at some places on the map by their sinuous ribbon-like form. Eskers are nearl all confined to the broad part of the Kent Moraine. Notable examples exist in Worth, northern Slippery Rock, and western Scott townships in Butler County; and in Springfield Township in Mercer County (Sitler, 1957, maps). The first of these is three miles in length. One esker north of the Kent Moraine exists in Sugar Run valley, Greene Township Mercer County.

Kames and kame terraces are found filling valley bottoms or ar perched along valley walls. Seldom are these features found on the flat upland surfaces. The thickness of these deposits is quite variable. Kames and kame terraces mapped along valley walls in some places co stitute little more than a thin blanket (0-10 feet) of sand and gravel. To ography on the surface of such blankets is relatively smooth compared the very knobby topography present on the thicker deposits. Good displays of kames and kame terraces occur in Erie County in and around Waterford, Union City, and Corry; and in Warren County in and north of Russell. These tracts extend across valleys and may have some relation to an ice edge which became "reorganized". They may even recor minor episodes of ice readvance. Several of these in northwestern nsylvania have been called "valley stopper moraines" by cClintock and Apfel (1944, p. 1158).

In Crawford County these features are well formed along the t wall of Pymatuning Swamp and Crooked Creek valleys between esville and Kennard, high up on the slope east of Conneaut Lake, nd around Mosiertown, Cussewago Township, north of Cochranton ng French Creek, and along the east side of Muddy Creek. Other able kames and kame terraces occur in Mercer County, south of nestown, along Pymatung Creek in Pymatuning Township, along kawannock Creek, south of Big Bend, and along the Little Shenango er and Sandy Creek, north and west of Sandy Lake. Numerous sand gravel areas constituting morainal kames occur within the Kent raine as shown on Plate 1.

wash (valley train) and lake deposits

Meltwater flowing from the stagnant ice deposited material along st of the valleys leading from the ice front as the ice decayed. These osits are now preserved as terraces at some distance above the pres- flood plains. No attempt was made on the map or during field work lifferentiate Kent valley train material from other age material. ailed work is required to trace the extent and composition of the Kent races as well as the terraces of earlier or later ages. The river ter-es in most places contain bedded sand and gravel with interbedded ds and rarely some silts and clays. The deposits are normally more form than are the kame or kame terrace deposits.

Extensive lake deposits were formed in front of the ice as it ved forward and progressively blocked north-flowing streams. An ensive system of lakes was formed in and around northwestern Butler nty as mapped by Frank W. Preston (1950). The largest and earli- lake has been called Lake Arthur by Preston. As the ice advanced e Arthur was reduced in size and split into two lakes called Lake nund and Lake Watts. These two lakes are shown on a map by ston (1950) reproduced here as Figure 11. Deposits of material rly filled both of these lakes and consisted for the most part of fine-bedded sands, silts, and clays. Lake Watts contained considerably r-grained material than did Lake Edmund. At Isle the deposits of e Watts are known to consist of 70 feet of clay overlain by three feet ilt. In Lake Watts the material becomes progressively coarser n Isle westward toward the front of the ice sheet. Lake Edmund was ed completely with coarser material. The levels of the two lakes in ms of present-day elevations were 1260 feet above sea level (Lake tts) and 1310 feet above sea level (Lake Edmund).

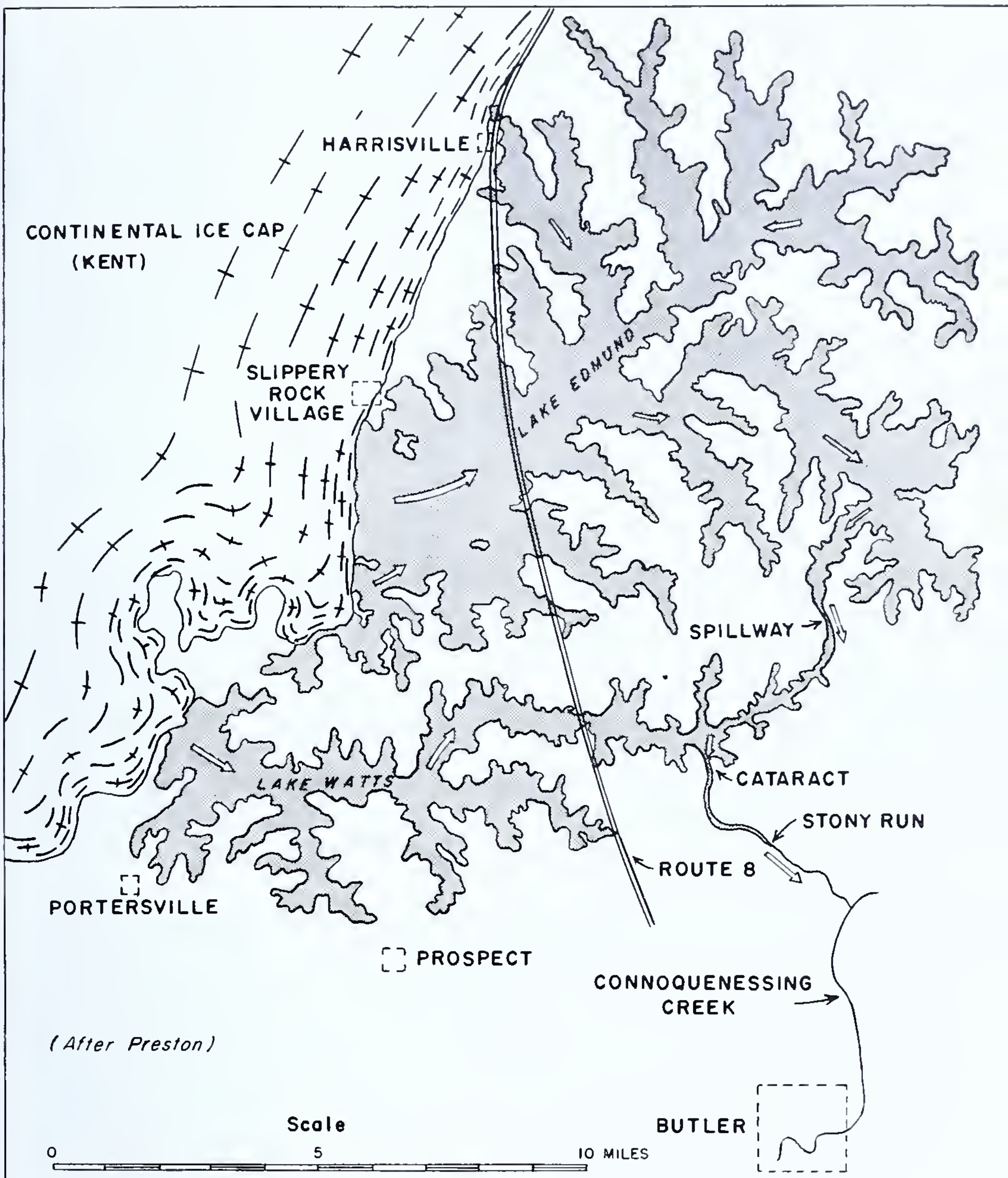


Figure 11. Distribution of glacial Lake Watts and Lake Edmund in front of the Kent ice sheet (after Preston, 1950).

LAVERY ADVANCE

General Statement

The Lavery advance followed the Kent advance in approximately middle Cary time. (Shepps, 1953; White, 1957; White, et al, 1957). An end moraine (the Lavery Moraine) was deposited along the margin of the Erie Lobe and a ground moraine was deposited to the north of the end moraine (Fig. 4 and Pl. 1). The advance and the end moraine were named by Shepps (1955) for the hamlet of Lavery in Erie County, four and one-half miles west of Edinboro on U. S. Route 6N. The type area for the moraine and the till is at and just north of Lavery where the moraine is well displayed along both sides of the highway and till in the roadcuts is typical of the till of the advance. The Lavery Moraine is part of Leverett's Cleveland moraine (Leverett, 1902, p. 619-651), but is renamed since the Cleveland moraine includes parts of four moraines and a number of non-morainic features. The Lavery Moraine is correlated approximately with the Fort Wayne-Wabash Moraine of Ohio (White, 1957).

The Lavery Till in the end as well as the ground moraine is a light-gray, moderately pebbly, calcareous silt till. It oxidizes to a dark-brown color. The average Lavery sample contains 31.24% sand, 47.03% silt, and 21.72% clay (Tharin, 1958, p. 31). The till ranges in size from 18 to 24 size factors with a mean size of 21.8 size factors (Fig. 8). There is no apparent change in texture from one part of the area to the other such as was present in the Kent Till, but the Lavery Till shows an overall increase in textural size from Ohio to Pennsylvania. As shown in Figure 10 the Lavery Till in Ohio has a mean size of 19.8 size factors as compared to 21.8 in Pennsylvania.

Depth of leaching in the Lavery Till averages approximately 45 inches with a variation from two to five feet. This leaching appears to be significantly less than the leaching on Kent Till and may be thought to indicate a much older age for the Kent than for the Lavery materials. However, the large difference may be more easily attributed to the difference in texture between the tills and the better overall drainage in the Kent areas rather than to a great age difference. The difference in leaching between Lavery and Kent materials is an aid in separating the two in the field.

Lavery Moraine

The end moraine of the Lavery advance, named the Lavery Moraine, extends from New York State diagonally across northwestern Pennsylvania and into Ohio (Fig. 4 and Pl. 1). The moraine ranges in width from one mile at the New York border to two miles or more in Spring Township in Crawford County. West of Spring Township, the

Lavery Moraine is buried by and compounded with the later Defiance Moraine. The relationship between the two moraines is not clear west of Conneaut Creek and an alternate interpretation is possible from that shown in Figure 4 and on Plate 1. It is possible that Lavery Till is at the surface throughout the southern quarter of the area mapped as Defiance Moraine, as appears to be the case to the west in Ashtabula County, Ohio. In this area washing by Defiance meltwaters has altered the surface material so that a great variety of materials is present and no till as such could be found. Since Lavery could not be separated from Defiance in this area the entire area is mapped as Defiance (Note: The area of possible Lavery Moraine is separated on the "Glacial Map of the United States east of the Rocky Mountains" (Flint et al, 1959). East of Conneaut Creek the Defiance Moraine has overridden only the inner edge of the Lavery Moraine.

Topography on the surface of the Lavery Moraine varies from smooth, hill and swale topography to moderately hummocky topography. Over much of its course the moraine is very subdued and in some places difficult to recognize. In the area around Lavery, the moraine is noticeably rolling and distinct mounds are recognizable. To the southwest and in places to the northeast of Lavery infrequent low hills and poorly-drained depressions mark the course of the moraine. Along much of the moraine the outer margin can be identified only by studying the surface material and the inner margin is in many places barely disconernible. The outer margin is defined in places by the presence of a weak marginal channel which may be best seen on aerial photographs. A marginal channel north of the road immediately west of Lavery is well shown on the photographs and can be seen on the ground. The moraine becomes somewhat better defined east of McKean and especially so after it becomes narrower east of Elk Creek.

Morainal kames exist at many places where the Lavery Moraine is deposited across a valley. Notable examples of these are located east of Pont, at and north of McLane, in Elk Creek valley north of Bagdad, and where LeBoeuf Creek is crossed by the moraine. The Lavery ice, much like the Hiram ice which followed it, sent narrow tongues of ice down valleys upon which it encroached. These tongues in some cases deposited ground moraine and in others deposited a kame moraine in front of the main end moraine. Ice in this form advanced down Carr Run at Hickernell; Cussewago Creek east of Pont; Conneautee Creek valley as far south as Edinboro and Elk Creek possibly as far south as Bagdad. Ice penetrated into other valleys, but not to the extent that an elongate ice tongue was formed. The most notable of the above tongues is the one which advanced into Conneautee Creek valley. Evidence indicates that the ice approached toward Edinboro from two directions as two tongues – one from McLane and the other down Shenango Creek valley. Whether the ice actually met, or whether the Shenango Creek tongue stopped at the kames is not known, but ice advanced to the position of Edinboro where it built a low kame moraine. An ice block, a part of the tongue, remained unmelted during the time while outwash from the north was filling the valley. Later melting of this ice block produced an ice block depression which filled with water to form Edinboro Lake.

Thickness of the Lavery material in the end moraine is poorly known. It appears to be rather thin on the uplands, but is thicker in the valleys. The thickness in the valleys doubtless does not represent all Lavery material. Thicknesses in the end moraine probably average 20 to 40 feet. In the valleys thicknesses of 50 to 100 feet are known and thicknesses greater than 100 feet have been reported in the kame moraine area north of McLane and in Elk Creek valley north of Bagdad. How much of this is pre-Lavery material is not known.

Ground moraine

The ground moraine of the Lavery advance consists, as does the end moraine, of silt till. The surface is smooth with very few undrained depressions. Thicknesses in the ground moraine are not known, but bedrock appears in many of the northflowing streams indicating that the material is not thick (10 to 30 feet estimated).

Kames and kame terraces

Deposits of glaciofluvial materials as kames or kame terraces are rare within the area of Lavery deposition except where deposited as kame moraine associated with the end moraine. The lack of glaciofluvial deposits may be attributed to the lack of south-flowing drainage outlets accessible to drainage from the ground moraine areas. Meltwaters from the ground moraine area must largely have been ponded or have moved sluggishly away parallel to the front of the ice.

Outwash (valley train) and lake deposits

Outwash was poured into all of the valleys which communicated with the moraine. The valley trains are preserved in most of the valleys as low terraces above the present flood plains. The most noticeable of the Lavery valley trains are those along Cussewago Creek south from Lavery and Crossingville; and along French Creek south of Mclane, along and south of Elk Creek and along and south of LeBoeuf Creek. Outwash appears to have been poured into ponded water in French Creek in the vicinity of Cambridge Springs, and possibly into ponded water in Cussewago Creek valley (Shepps, 1959). Remnants of delta-like deposits are present in Cussewago Creek valley to suggest ponding at some time during Lavery time. In French Creek valley ponding is indicated by the flatness of the valley bottom north and east of Cambridge Springs. The level of the water in this area would have been controlled by the levation of the outlet between Cambridge Springs and Saegertown for rench Creek must have been diverted through this channel prior to the avery advance. Deposition of materials in French Creek valley be ween Cambridge Springs and Edinboro exceeds 200 feet in thickness n places although this is not necessarily all Lavery material. Depth o bedrock in Cussewago Creek valley is known to exceed 200 feet in he northern parts near Mosiertown and near the junction of Cussewago reek and French Creek at Meadville depths greater than 400 feet have een reported (Leggette, 1936, p. 126).

Exposures of the valley train materials are rare, but gravel its along French Creek at Meadville and along Conneautee Creek south f Edinboro show bedded, well-sorted sands and sandy gravels.

HIRAM ADVANCE

eneral Statement

The advance of Hiram ice occurred toward the end of Cary time fter the Lavery ice had retreated some distance to the north, prob- bly completely out of the Erie Basin. The Hiram advance deposited an nd moraine (Defiance Moraine) along the margin of the ice (in Penn- ylvania and extreme eastern Ohio; farther west in Ohio the Hiram till xtends beyond the Defiance Moraine) and ground moraine. The Hiram ce, like the Lavery ice, was sufficiently plastic to send tongues for any miles down the valleys upon which it advanced. The advance was amed by White from the village of Hiram in Portage County, Ohio near hich the Hiram till is well displayed (White, in press). The Defiance Moraine was originally named the Blanchard Moraine after a river by hat name in northwestern Ohio. The name Blanchard was gradually replaced by the name Defiance for the town and county of the same ame in northwestern Ohio through which the moraine passes. The Defiance Moraine has been traced from the type area at Defiance across hio and into Pennsylvania (Leverett, 1931, Fig. 8). Though the relationships of the Defiance Moraine are not everywhere clear, the moraine called Defiance in Pennsylvania is believed to be correlative with the moraine which passes through Defiance, Ohio. It is correlative with the Defiance ("late Cary") Moraine of White in eastern Ohio (White, 1953 a, Pl. 8).

The Hiram Till is a gray to bluish-gray, sparingly pebbly, calcareous, clay to silty clay till, which oxidizes to a drab brown color. In general the till is more clayey toward its margins and becomes increasingly silty northward. The average Hiram sample contains 13.65% sand, 50.60% silt, and 35.75% clay (Tharin, 1958, p. 31). The till has a mean size of 15.1 size factors and a range in terms of size factors from 9 to 19 (Fig. 8). Part of the apparently large variation is accounted for by the increase in coarseness of the till northward. The Hiram Till of Pennsylvania is very similar to the same till in northeastern Ohio which has a mean size of 14.5 (Fig. 10).

The Hiram Till is easily distinguished from the other tills of northwestern Pennsylvania by its fine-grained texture, scarcity of pebbles, drab brown color, and the fact that a structure develops in the subsoil which gives a checked appearance to the till in road cuts. Depth of leaching in the Hiram Till where measured averages 45 inches and ranges from 3 to 4.5 feet. These figures for the till as a whole are somewhat high since measurements are more numerous in the moraini and well drained areas. Depth of leaching in the same till in Ohio where samples are largely from the ground moraine averages three feet. A similar figure would probably apply for the Hiram Till in Pennsylvania if most of the samples had been taken from the ground moraine.

Defiance Moraine

The end moraine of the Hiram advance, called the Defiance Moraine, trends diagonally across northwestern Pennsylvania from the Ohio line on the west,northeastward until it is buried beneath the later Ashtabula moraines in Summit Township, Erie County. East from Summit Township the moraine again appears from beneath and south of the Ashtabula moraines just at and on the New York side of the Pennsylvania border. From the Ohio border to McKean Township the Defiance Moraine is deposited on top of or partially on top of the earlie Lavery Moraine and is consequently compounded with the Lavery Moraine in these areas. Here, as in adjacent Ohio, the Defiance Moraine owes its form to the underlying Lavery Moraine. East of Franklin Township, where the Defiance Moraine is not compounded with the Lavery Moraine, it is very subdued and nearly indiscernible.

The Defiance Moraine from the Ohio line to Springville forms a moderately constructional, locally hummocky, two-to three-mile-wide band. As previously noted the southern quarter of what is mapped as Defiance Moraine may actually be Lavery Moraine. The Defiance Moraine in the vicinity of Dicksonburg in Conneaut Creek valley is a kame moraine. East from Springfield the moraine is extremely subdued and is traced largely on the basis of field identification of the till combined with field and aerial photograph examination of ground versus end moraine. The end moraine east of Springboro is a very slightly constructional, weakly hummocky 1-to 1.5-mile-wide band with rare undrained depressions. Both the back and front borders of the moraine along this band are elusive. The Defiance Moraine with moderately constructiona topography appears at the New York border and is identified as Defianc by the character of the contained till.

round moraine

The ground moraine of the Hiram advance consists of silty clay ll which is locally clayey. The till appears to be discontinuous, a con- ition which was found in Ohio (White, 1953 b),and in some places the oils are developed on Lavery Till or on Hiram Till which occupies nly the upper foot or so of the soil profile. The surface of the ground oraine is flat and contains only rare undrained depressions or oorly drained areas.

Ground moraine is found, in addition to the normal deposits ehind the Defiance Moraine, in a position outside of the end moraine. ear Conneaut Lake deposits of clay till with shallow leaching have een identified and mapped as Hiram Till (Pl. 1). These were depos- ed by a body of ice which moved as a tongue down the valley of Con- eaut Creek in advance of the main ice mass which deposited the Defi- nce Moraine. The tongue of ice is noteworthy for the fact that it oved for a distance of eight miles down a valley which was only two iles wide. In so doing the tongue assumed the characteristics of a alley glacier leaving behind typical valley glacier deposits. Till as uch was deposited only along the outer edge of the ice tongue when it as at its maximum extent. As shown on Plate 1 an area of end mo- aine occurs within a larger patch of ground moraine southwest and est of Conneaut Lake. The end moraine in this area exhibits a mod- rately hummocky to rolling surface in contrast to a relatively smooth urface on the ground moraine. Both end and ground moraine are com- osed of clay till.

A similar ice tongue appears to have advanced into an area round the southern end of Pymatuning Reservoir north of Jamestown Pl. 1). Clay till with shallow leaching is found in this area in associ- tion with glaciofluvial deposits which show shallow leaching.

ames and kame terraces

Ice contact glaciofluvial deposits, except for kame moraine ssociated with the Defiance Moraine, are rare in the Hiram drift reas. The only kames of note in the ground moraine area are in emple Creek valley north and south of Lundys Lane in Elk Creek ownship. Kame moraines associated with the Defiance Moraine are ell developed in Conneaut Creek valley, at Steamburg, and at Pont. ames, kame terraces, and a kame moraine were deposited by the ongue of ice which pushed down Conneaut Creek valley. A well devel- ped kame terrace was deposited along the east side of Conneaut Lake xtending north past Harmonsburg. A kame moraine completely plugs he valley at the head of Conneaut Creek. The southern part of this ame moraine has developed upon its surface a series of long, linear, arallel ridges of the sort which would be formed along the front of an active valley glacier. Kames were deposited along with the till moraine just west of Conneaut Lake. Kames, a possible kame moraine, were deposited at the front of the ice tongue which moved into the Shenango River valley near Jamestown.

Depth of leaching in Hiram kames averages approximately six feet. This is similar to the leaching in the Lavery and Ashtabula glaciofluvial deposits, but is in contrast to the much greater leaching (average 14 feet) in the Kent glaciofluvial deposits. It is the depth of leaching in the tills as well as in the glaciofluvial deposits that support the conclusion that these materials were deposited by a tongue of ice which moved south down the Shenango Creek valley to Jamestown.

Outwash (valley train) and lake deposits

Outwash poured down Padan Creek and the creek north of Linesville into the Shenango River valley into what may have been a ponded situation. With an ice tongue at Jamestown the upper Shenango River valley would presumably have been dammed so that a lake would have formed which had its outlet across a low col near Adamsville. Materials exposed in the vicinity of Pymatuning Reservoir are for the most part fine-grained, supporting the idea that a lake existed in the area of Pymatuning Reservoir. If a lake did exist it apparently was short-live and was drained before it was completely filled.

Outwash also poured into Conneaut Creek and Conneaut Outlet valleys, but because of the existence of an ice tongue in those valleys the history and depositional pattern of the outwash is complex. The position of the ice front in the valley stood at different places at different times. The front of the tongue first stood at a position just south o the town of Conneaut Lake. From this position it presumably poured outwash into Conneaut Outlet, but only for a short time. The ice then stagnated and melted down and back to a position at Harmonsburg Station from which place outwash was poured south into the Conneaut Lake area to form a wide, flat, south-sloping outwash plain typical of a valley glacier. An unmelted ice block in the position of Conneaut Lake prevented filling of the valley by outwash in that place and its melting later formed the depression which is Conneaut Lake. After formation of the kame moraine and outwash plain at Harmonsburg Station the ice stagnated and began to melt in Conneaut Creek valley. Meltwaters from the decaying of the main ice mass to the north were ponded up to the level of the outwash plain at Harmonsburg Station and the lake formed by this ponding was filled with silts and clays which in some places are varved. The lake sediments in the area south of Conneautville were deposited within channels formed between blocks of partially decayed ice which apparently remained in the valleys throughout the lifetime of the lake. When the ice blocks later melted, the lake sediments slumped so that an apparent knob and kettle topography was formed on the surface (Shepps, 1953; 1959).

ASHTABULA ADVANCE

General Statement

The Ashtabula advance occurred very near the close of Cary time. It was an advance of the Erie Lobe which did little more than fill the Erie Basin; it did not form a Grand River Sublobe in Ohio or Pennsylvania. Its limit is marked by a prominent series of end moraines that extend from Cleveland, Ohio across northwestern Pennsylvania into New York. This advance is named from the till that it deposited, called "Ashtabula Till" (White, in press) from excellent exposures at Ashtabula, Ohio.

The till of the advance is a gray to bluish-gray, moderately pebbly, silt till which has an average composition in Pennsylvania of 1.34% sand, 45.51% silt, and 23.35% clay (Tharin, 1958, p. 31). The mean size of the till is 21.8 size factors with a range from 18 to 25 size factors (Fig. 8). A detailed study is being made at this time to show the variation in the texture of the Ashtabula Till from Cleveland, Ohio to the Pennsylvania-New York line. It is known in a general way that the tills become progressively coarser from west to east. As noted before the till is very similar texturally to the Lavery Till. Depth of leaching in the Ashtabula Till averages 47 inches with a known variation from three to five feet (Shepps, 1955, p. 26). Although this till is younger than the Lavery Till and of the same average texture, the depth of leaching is greater on the average. This can be attributed to overall better drainage conditions. Since no ground moraine is present in Pennsylvania for the Ashtabula advance, no leaching measurements were made in potentially poorly drained areas such as in the Lavery ground moraine. The younger age of the Ashtabula materials shows up in studies of the soil development. Measurements on thickness of the A horizon (Shepps, 1953, p. 27) show that the Ashtabula tills average 8.5 inches compared to 12.7 inches on the Lavery tills.

Ashtabula Morainic System

The Ashtabula advance was not a single one, but deposited en echelon a series of moraine ridges parallel to the shore of Lake Erie and, east of Albion, against the foot of an escarpment formed upon resistant beds in the Conneaut Formation. These ridges are everywhere well developed and exhibit bold knob and kettle topography. This group of moraine ridges was called the "Lake Escarpment Morainic System" by Leverett (1902, p. 651) and earlier by the present authors (Shepps, 1953; White, 1957; White, et al, 1957). One of the principal ridges was called the "Ashtabula Moraine" by Leverett (1902) from its excellent development at Ashtabula, Ohio. Farther east, at the New York State line and in New York, the "Lake Escarpment system" of Leverett is made up of separate moraine ridges not only of the Ashtabula advance, but also includes a Defiance Moraine element of the Hiram advance and a Lavery element as well. It seems preferable, therefore, to adopt a geographic name for that part of the morainic system composed of till of the Ashtabula advance and to extend Leverett's name "Ashtabula", given to one of the prominent end moraine ridges, to the "Ashtabula Morainic System".

Within the morainic system in positions between the various moraines are found low, relatively featureless areas which, although possessing meager outwash materials, represent drainageways for meltwaters. Material in these areas varies from till to washed till to glaciofluvial materials and consequently is not entirely outwash. These areas have not been separated in Plate 1, but are mapped in part by Leverett as outwash (Leverett, 1902, Pl. XVIII). The thickness of the material over the bedrock in the area of the Ashtabula moraines, based upon the information at hand, is generally between 40 and 80 feet, but is known to exceed 100 feet in places. The material is not necessarily all Ashtabula Till since earlier tills and glaciofluvial materials may be buried at depth.

In an area east of Erie, mapped as Ashtabula Moraine under thin beach sands, the moraine has been reduced by erosion when it was covered by the waters of a post-Ashtabula lake. A thin layer of lake sediments covers the eroded surface, but the deposition and erosion have not been sufficient to completely subdue the constructional topography of the buried moraine.

Glaciofluvial deposits

Kames are rare in the Ashtabula moraines in the western part of the area, but become very common to the east. Outwash occurs as low terraces along streams or as low flat channel-like areas between the separate moraines. As noted above some of these low, flat areas do not contain outwash materials predominantly and have not been mapped as outwash. Meltwaters from the successive moraines drained westward between the previous moraine and the moraine being formed or broke through the previous moraine and flowed outside of it. Conneaut Creek over much of its course has followed the drainageway between two moraines. The fascinating and complex history of meltwater drainage (to higher and earlier lake levels) can be easily seen on the topographic maps of the area.

POST-CARY DEPOSITS

GENERAL STATEMENT

Ice advances after the Ashtabula advance which occurred elsewhere during Mankato, Valders, or Port Huron time failed to reach Pennsylvania. The advent of such advances is recorded in northwestern Pennsylvania by lake deposits laid down in higher level lakes in the Erie Basin. In addition to these deposits swamp deposits including peat in some places, and stream alluvium have been forming up to the present time.

LAKE DEPOSITS

Leverett (1902, Chaps. 24, 25, 26, and 27) has discussed in detail the history of the early lakes in the Erie Basin, the deposits of hese lakes, and their history. More recently Hough (1958) has summarized the lake history. The waters of the various lakes worked upon he pre-existing sediments, most of which were tills, and upon the bedrock where it was exposed. This produced along the southern shore of present Lake Erie a 2.5-to 4-mile-wide plain on the surface of which are blanket deposits of sands, silts, and clays; and a series of beach ridges at different elevations which contain sands, and gravelly sands. Leverett shows the location of the various beach ridges, their names, elevations, and the names of the lakes in which they were deposited Leverett, 1902, Pls. XV and XVIII).

A short discussion of the deposits of the lake plain is given in a report on the water resources of the region (Mangan, et al, 1952, p. 28-30). A section through the lake plains is also given although he drift is not differentiated. Most of what is shown as drift in this section is till which is capped by a blanket of sand and gravel with some finer sediments and which is thicker under the beach ridges. The thickness of the deposits over most of the lake plain varies between 10 and 75 feet. Deposits are more than 100 feet thick along the course of a buried valley which runs between Albion and Springfield Station and just east of North Springfield. The deposits are thinnest ust east of Erie.

SUMMARY AND GLACIAL HISTORY

Extensive ice sheets moved down the Erie Basin into northwestern Pennsylvania and easternmost Ohio as a tongue of the major Erie Lobe of ice called the Grand River Lobe. During the last ice advance, no distinct Grand River Lobe formed, and invasion of Pennsylvania occurred as lateral spreading of the Erie Lobe itself.

The first recorded ice advance into northwestern Pennsylvania occurred during the Illinoian age of the Pleistocene Epoch. Two advances entered Pennsylvania during this time, the second stopping short of the first in many places. Till and glaciofluvial materials were later largely removed by subaerial and subglacial erosion.

During the Wisconsin age of the Pleistocene Epoch the ice advanced first during Tazewell time and deposited a coarse, sandy till blanket. After retreat of the Tazewell ice a period of frost action and weathering modified the top of the Tazewell deposits. Ice advanced four times during Cary time; each successive advance had less vigor and stopped short of the previous margins. The first (Kent) ice invasion occurred near the beginning of Cary time, spread out nearly to the earlier Illinoian limits and deposited a loam till as an extensive blanket and as a bold end moraine. Water activity during melting of this ice sheet formed extensive outwash deposits as kames, kame terraces and eskers, and filled most of the major valleys in front of the ice margin with thick valley train deposits.

The Kent ice stagnated and melted back to some position in Canada, then readvanced toward middle Cary time (Lavery) and again encroached on Pennsylvania. The ice stopped many miles behind the previous Kent border and a silt till was deposited along with some kames and valley train deposits. Tongues of ice moved ahead of the main ice front into communicating valleys and formed morainal loops which blocked or restricted the valleys.

After a short retreat into Canada to a position probably barely out of the Erie Basin, the ice readvanced late in Cary time (Hiram). The ice of this advance brought with it a clay till which was deposited over the landscape behind and in some places upon the previous Lavery Moraine. As with the Lavery advance, the Hiram ice border was marked by tongues of ice which moved ahead for sizeable distances into valleys which communicated with the ice front. Along with morainic loops laid down by these tongues, lake deposits were formed where waters were impounded by the tongues or by their deposits.

The Hiram ice melted back for some distance into Canada and then again readvanced near the close of Cary time. This readvance (Ashtabula) entered northwestern Pennsylvania for only a short distance and formed en echelon a series of bold end moraines of silt till parallel to Lake Erie.

Later ice advances failed to enter Pennsylvania, but approached sufficiently close to back up waters in the Erie Basin to form a succession of high-level lakes. The higher waters reworked the previously laid till deposits and deposited sand and gravelly sand as blanket deposits and beach ridges along a wide plain south of the present shore of

Lake Erie. During all of the time that northwestern Pennsylvania was free of ice the previously deposited materials were subjected to subaerial erosion and weathering, and were locally worked and redeposited as stream alluvium or as lake and swamp deposits.

ECONOMIC RESOURCES

GENERAL STATEMENT

Materials of economic value are to be found in the glacial deposits of northwestern Pennsylvania. Abundant quantities of sand and gravel are known to exist and the prospects for finding usable clay are promising. Water supplies ranging from small domestic quantities to large industrial supplies are available from the glacial deposits.

SAND AND GRAVEL

Areas mapped as "k" (kames, kame terraces, kame moraine, and eskers) on Plate 1 contain mounds or linear ridges and, rarely, blanket deposits of poorly sorted, washed materials. These materials, deposited in the form of irregularly stratified beds and lenses, comprise sands and gravels with minor amounts of silt and clay, till in the form of irregular masses, and scattered boulders. The deposits contain sandstones, quartzites and siltstones with smaller amounts of igneous and metamorphic rocks, limestone, and some chert. For most uses, except for fill and embankment material, screening and washing will be required to obtain selected size material. Since these deposits are nearly always located on or at the top of a slope, groundwater seldom hinders operations. Most of the gravel operations in northwestern Pennsylvania are in these deposits.

Areas mapped as "ol" (outwash, etc.) on Plate 1 contain bedded gravels, sands, silts, and/or clays. In most places the deposits contain well-bedded sands and gravelly sands which are well sorted. Silts and clays are usually restricted to lake deposits many of which have been noted above. One exception is with the lake deposits on the plains south of Lake Erie. These contain sands with some gravel and minor amounts of silt and are thickest under the beach ridges (Mangan, et al, 1952, p. 29). In general, screening will be required to obtain limited grade sizes, but, in some cases, persistent beds of limited grade size material may be found. As a rule, valley train material becomes finer as one moves away from the source. Rock types contained in this unit are similar to those described in the paragraph above. Many of these deposits, especially those located in valley bottoms, are saturated with water. This factor should be carefully considered when evaluating a contemplated operation in this material. Most of the existing gravel operations in these deposits are in terraces along the major rivers.

CLAY

No clays as such have been tested to determine their usefulness and no specific locations are known. However, certain areas may be cited as likely to contain clays which may be of some value. The tills have been shown to contain largely illite and chlorite in the clay fraction (Droste and Doehler, 1957). Clays derived from the tills and deposited as lake sediments can be expected to contain these clay minerals in their unweathered portions. The clays will probably be quite plastic, have good green strength, moderate to high shrinkage and will fire at a low temperature (cone 08 to 5 estimated).

The Hiram Till in the Hiram ground moraine and in the Defiance Moraine contains a large proportion of clay and may be found useful for the manufacture of common brick or tile. Investigation of the lake deposits associated with the Hiram Till may reveal clay beds. Likely areas for such deposits are in and around Conneautville and west and southwest of Albion. Clays are reported to compose the sediments formed in Lake Watts (Fig. 11) except where near the Kent Moraine, and may make up a part of any of the lake deposits mentioned above.

GROUNDWATER

A study of the groundwater available in northwestern Pennsylvania has been published (Leggette, 1936) which includes a description of important wells and the expected sources of water in each county. In addition a map of the valleys in northwestern Pennsylvania which have been buried (filled in) by glacial deposits is furnished. A short report on the groundwater available along the Erie shore region was published in 1952 (Mangan, et al, 1952). The discussion here is intended only to point out the gross aspects of the groundwater situation in the glacial deposits.

Domestic supplies of water (3 to 5 gallons per minute) are encountered in most wells penetrating glacial material. Wells in till derive water from sands and gravels interbedded in the till or from coarse material at the till-bedrock contact. Till as such is generally impermeable and yields very little water. Large supplies of water are not normally found in the till areas except where a valley has been buried (Leggette, 1936, Pl. 2). Potentially large quantities of water are to be found in the buried valleys and in existing valleys which contain a fill of outwash, kame material and in some cases lake deposits. One dug well at Oil City is reported to yield 2000 gallons per minute from valley-fill deposits (Leggette, 1936, p. 197). Two drilled wells at Meadville in valley-fill deposits each yield approximately 2500 gallons per minute (Leggette, 1936, p. 126). Yields such as these are unusual, but yields of 300 to 700 gallons per minute can often be obtained from the valley-fill or buried valley deposits with a properly installed well.

GLOSSARY

Buried valley. A preglacial or early glacial valley which has been partly or completely filled with glacial drift.

Calcareous. Containing calcium carbonate.

Colluvium. Loose and incoherent material moved down a slope by gravity.

Constructional topography. A land surface formed as a result of the processes of deposition.

Corrugation topography. A glacially formed land surface exhibiting long, linear, parallel ridges and valleys elongated in the direction of ice movement.

Crevasse filling. An elongate deposit of sand and gravel believed to have been deposited in a crevasse in melting ice.

Depth of leaching. The depth to which calcium carbonate has been removed from a deposit by weathering processes.

Depth of oxidation. The depth to which ferrous compounds in a deposit have been altered to brown (ferric) oxides by weathering processes.

Drift. Any rock material deposited by an ice sheet or by meltwaters of that ice sheet.

Drumlin. A streamlined, spoon-shaped hill of till formed under a moving ice sheet and elongated in the direction of ice movement.

End moraine. A ridgelike deposit of till formed at the front of an ice sheet.

Erosional topography. A land surface formed by the processes of erosion.

Erratic. A rock fragment different from the bedrock over which it lies and either separate or enclosed in drift.

Esker. A long, narrow, commonly sinuous ridge composed of sand and gravel, presumably deposited in a subglacial tunnel from meltwater.

Glaciofluvial. Pertaining to streams flowing from glaciers or to the deposits made by such streams.

Ground moraine. A moraine with low relief, devoid of transverse linear elements.

Ice block depression. A hole remaining when an ice block, buried wholly or partly by drift, melts.

Interglacial. Pertaining to the time between major glacial advances.

Interstadial. The time during which an area is free of ice as a result of fluctuations in the margin of a major ice sheet.

Kame. A mound composed chiefly of sand and gravel deposited in contact with the ice by meltwaters.

Kame field. A group of closely associated or interconnected kames. A kame complex.

Kame moraine. An end moraine composed largely or wholly of kames.

Kame terrace. A linear group of kames, having at times a terrace-like appearance, deposited from meltwaters in the fosse between glacial ice and a valley wall.

Knob and kettle topography. A surface exhibiting knobby hills with interspersed undrained depressions.

Leaching. See depth of leaching.

Loam. A material composed of approximately equal parts of sand, silt, and clay-size particles.

Marginal channel. A channel formed by meltwaters flowing along an ice margin.

Moraine. An accumulation of till possessing an initial constructional topography independent of the surface upon which it was deposited.

Morainal kame. A kame which is an integral part of an end moraine.

Outwash. Stratified drift deposited by meltwater streams.

Outwash plain. A deposit of outwash whose surface is a broad, very gently sloping plain.

Oxidation. See depth of oxidation.

Periglacial. Pertaining to a belt of terrain of indeterminate width adjacent to the margin of a glacier (usually an ice sheet).

Preglacial. Of, pertaining to, or occurring in geologic time before the glacial epoch.

Profile of weathering. A succession of subzones in the upper part of a deposit produced by weathering, particularly chemical alteration.

Proglacial. Pertaining to features of glacial origin beyond the limits of the glacier itself.

Recessional moraine. An end moraine in a position behind the terminal moraine of any given ice advance. These are formed when, during the ice front recession, there is a temporary readvance.

Size analysis. The study of a sample to determine its particle size distribution (texture).

Subaerial. Formed, existing, or taking place at a surface which is exposed to the atmosphere.

Subglacial. Formed, existing, or deposited under a glacier.

Terminal moraine. The outermost end moraine deposited by any given ice sheet.

Till. A nonsorted, nonstratified sediment carried or deposited by a glacier.

Till texture. The size distribution of the component grains in a till.

Valley train. Outwash deposited as a long, narrow band confined within a valley which carried a stream of meltwater flowing away from the ice.

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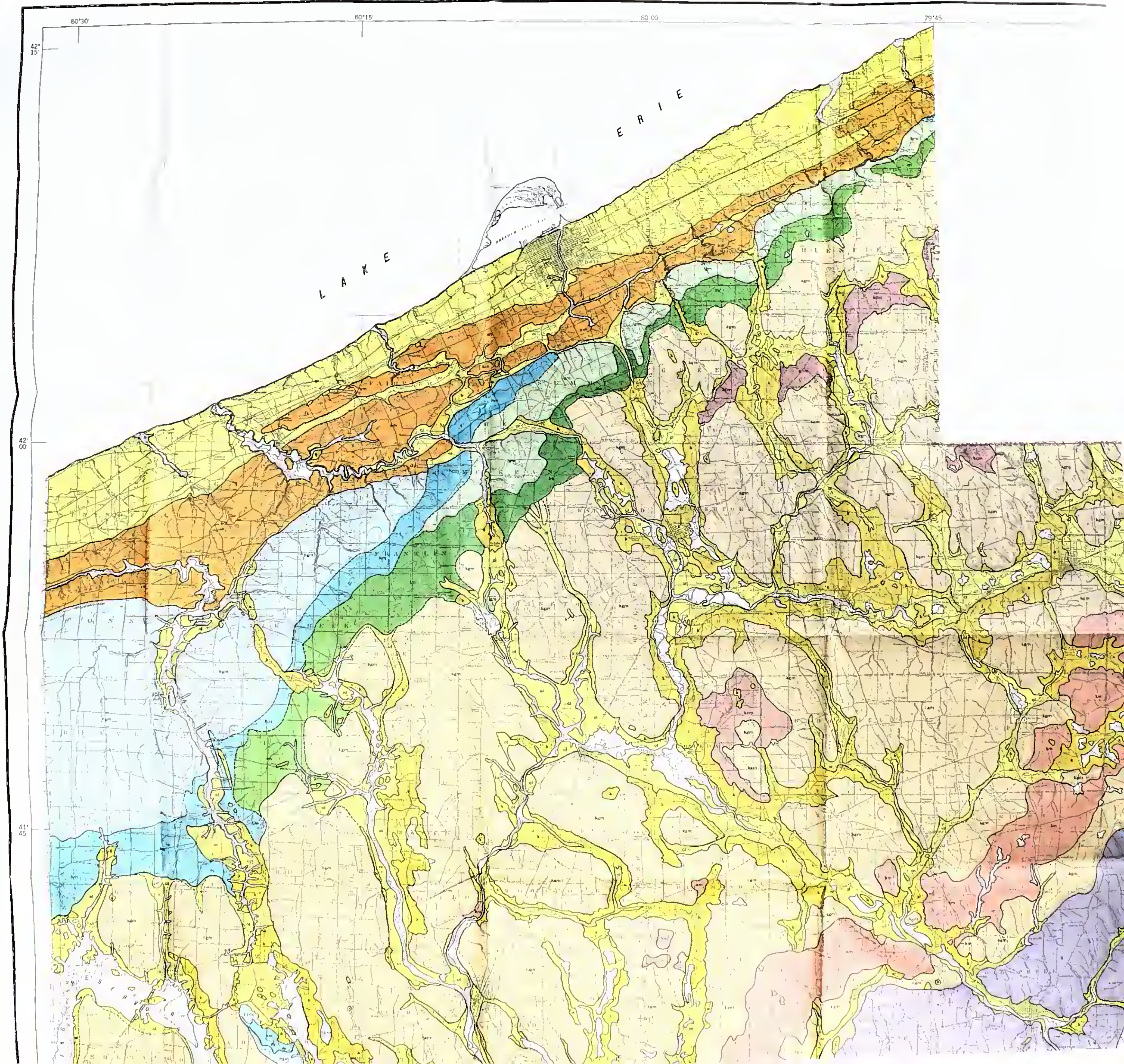
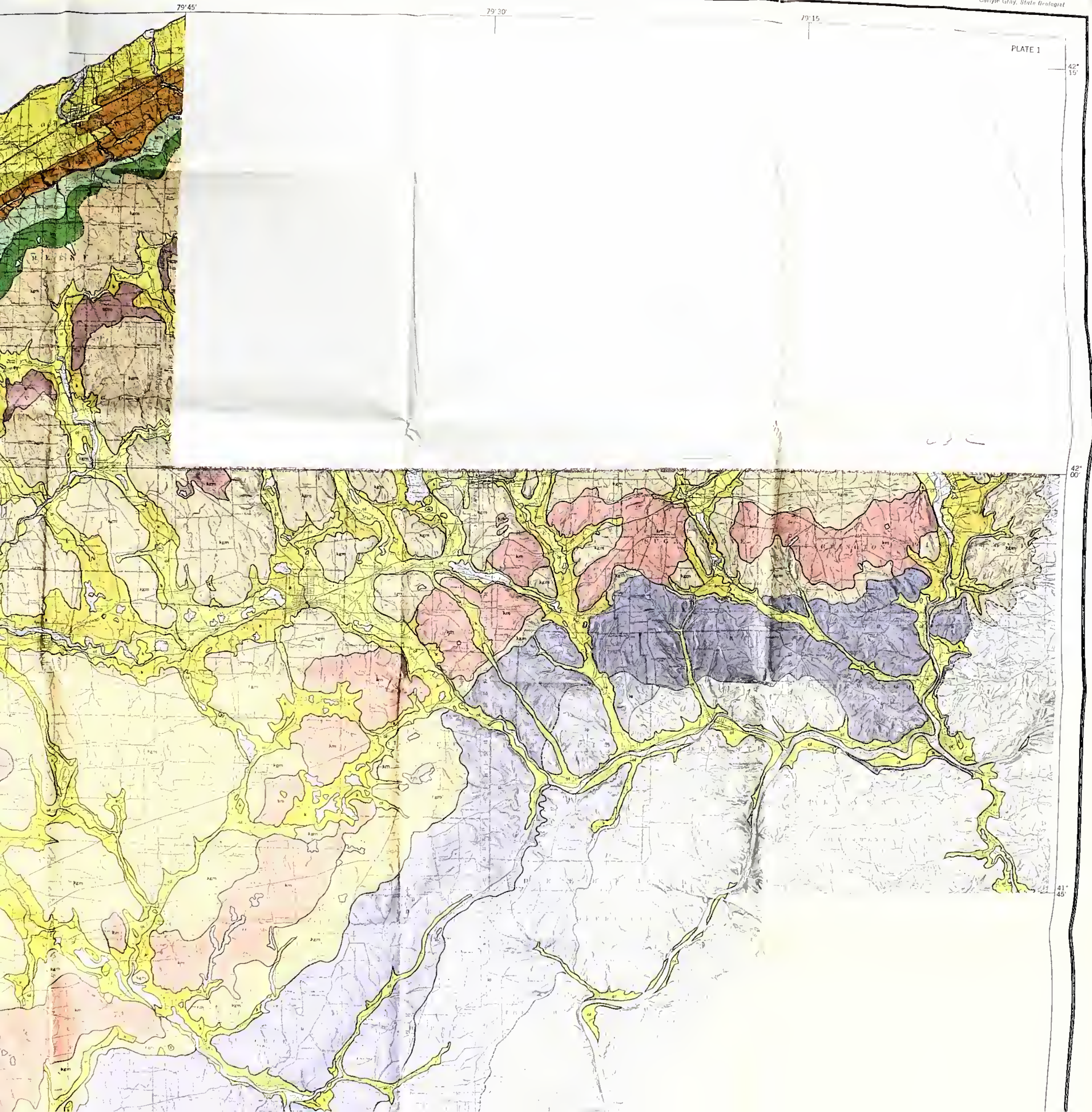
OMMONWEALTH OF PENNSYLVANIA

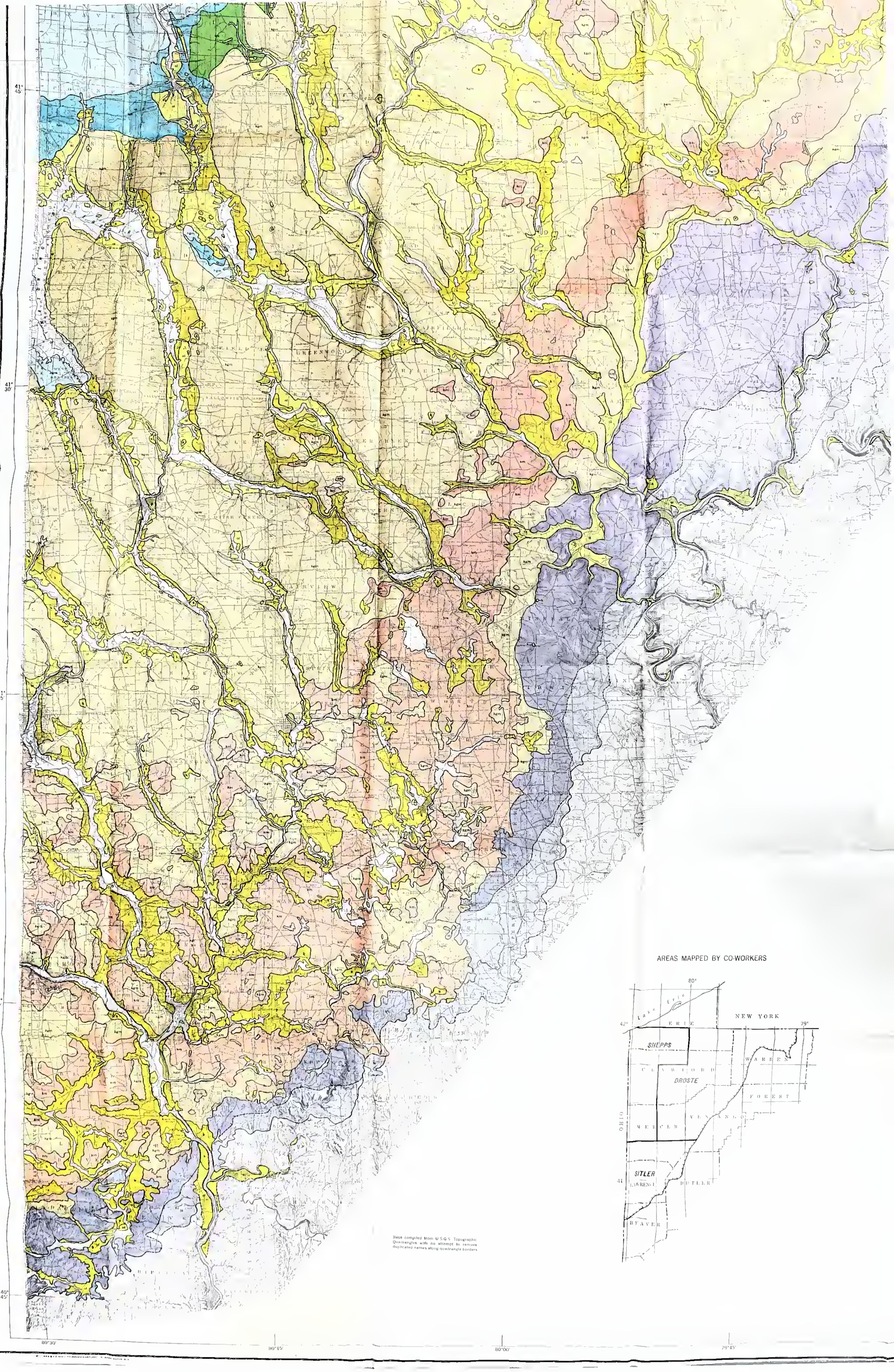


COMMONWEALTH OF PENNSYLVANIA

TOPOGRAPHIC AND GEOLOGIC SURVEY
Carlyle Gray, State Geologist

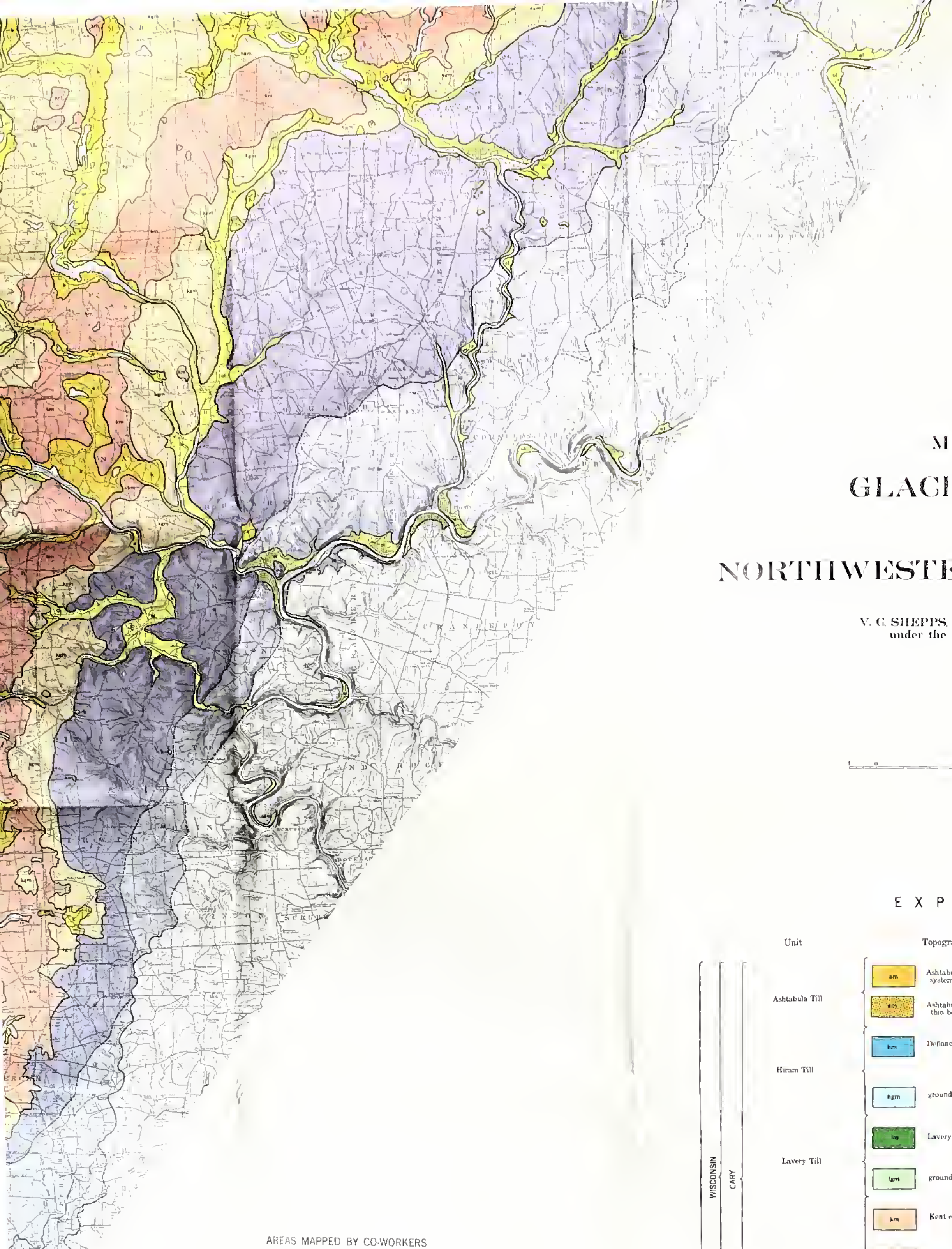
PLATE 1





AREAS MAPPED BY CO-WORKERS

Base compiled from U S G S Topographic Quadrangles with no attempt to remove duplicated names along quadrangle borders



MAP OF THE GLACIAL DEPOSITS OF NORTHWESTERN PENNSYLVANIA

BY
V. C. SHEPPS, J. B. DROSTE, and R. F. SITLER
under the supervision of G. W. WHITE

1959

SCALE
1/125,000
1 0 5 10 Miles

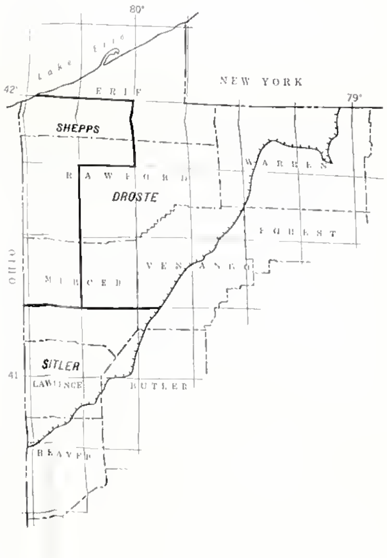
Contour Interval – 20 feet

EXPLANATION

			Unit		Topographic Features	Character of Material	Topography
PLEISTOCENE	WISCONSIN	CARY	Ashtabula Till	am	Ashtabula moraine system (end moraines)	Till (silt)	Strongly constructional; knob and kettle topography; numerous undrained depressions
				am	Ashtabula moraine under thin beach sands		
			Hiram Till	hm	Defiance end moraine	Till (silty clay to clay)	Undulating; locally constructional; scattered undrained depressions; very weak at places
				hgm	ground moraine	Till (silty clay)	Flat to gently undulating; local poorly drained areas
			Lavery Till	lm	Lavery end moraine	Till (silt)	Somewhat undulating; locally constructional; undrained areas rare
				lgm	ground moraine	Till (silt)	Level to gently undulating
			Kent Till	km	Kent end moraine	Till (sandy loam)	Strongly constructional; knob and kettle topography; numerous undrained depressions
				kflm	Findley Lake recessional moraine	Till (loam)	
				kcm	Clymer recessional moraine	Till (loam)	
				kgm	ground moraine	Till (loam becoming sandy loam toward the east and southeast)	Smooth to gently undulating; undrained areas very rare
	ILLINOIAN		Inner phase	Ii	ground (?) moraine	Thin, discontinuous, weathered till blanket	Erosional; similar to non-glaciated area, but less "rugged", rare slightly constructional patches
			Outer phase	Io	ground moraine (?)	Rare patches of thin weathered till over bedrock; scattered erratics	Erosional; similar to non-glaciated area, but slightly less "rugged"
	ILLINOIAN OR WISCONSIN		Undifferentiated members of units above	k	kames, kame terraces, kame moraines, and eskers	Sand and gravel	Distinctly constructional except in Illinoian areas. Knobby; commonly in the form of ridges, terraces, or isolated mounds; kame moraines intimately mixed with end moraines
			Undifferentiated members of units above	ol	outwash (valley trains), river terraces, lake deposits including beaches of former high levels of Lake Erie	Bedded sand, silt, and clay; sand and gravel	Generally smooth to gently undulating; commonly nearly level or gently sloping downstream
RECENT OR PRE PLEISTOCENE			Undifferentiated	☐	stream alluvium and bedrock		

NOTE – The symbols above are normally prefixed by the letter "Q" for Quaternary. The letter has been omitted since all units having symbols are of Quaternary age. Glaciofluvial deposits outside the glacial border are only partially mapped

AREAS MAPPED BY CO-WORKERS



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FOURTH SERIES